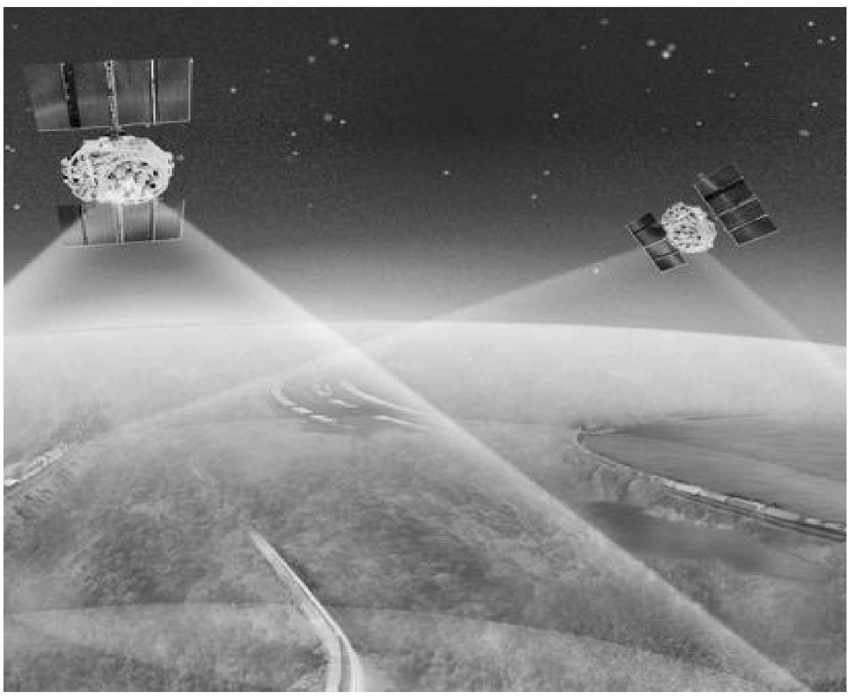
Report of the Railroad Safety Advisory Committee

to the

Federal Railroad Administrator



Implementation of Positive Train Control Systems

September 8, 1999

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Abstract

This Report of the Railroad Safety Advisory Committee (RSAC) describes the status of efforts to develop, test, demonstrate and deploy Positive Train Control (PTC) systems and describes actions that should be taken to provide an appropriate climate for implementation of those systems. The report focuses on the safety dimensions of PTC, but also addresses other benefits that railroads and the society at large may realize if PTC is implemented successfully and at a sustainable cost. The report sounds a cautionary note, because railroads and suppliers are currently estimating very substantial costs for implementation of the more capable forms of PTC. Many railroads believe that they have identified means of enhancing the efficiency of their operations and the quality of their service without the necessity of deploying PTC systems, as such.

On the other hand, planned investments in enhanced computer-aided dispatching, locomotive cab electronics, and position tracking could be expected to reduce the cost of implementing PTC systems in the future, and today's substantial costs for wayside components could be expected to decline when firm investment decisions are made on a large scale. Accordingly, the RSAC will continue to support efforts to promote and develop PTC systems. The major freight railroads have joined the State of Illinois and the Federal Railroad Administration (FRA) in launching development of a version of PTC that could serve as the foundation for mixed freight and high-speed passenger operations, providing enhanced system capacity as well as ensuring a very high level of safety. Other planned safety-relevant projects, which in general are intended to "overlay" rather than replace the primary means of controlling trains and protecting roadway workers, will be evaluated to ensure that they will achieve acceptable levels of safety when implemented. The Committee recommends additional actions that can contribute to a favorable climate for deployment of PTC systems in the future.

Background

Since the early 1920s, systems have been in use that can intervene by warning crews or causing trains to stop if they are not being operated safely because of inattention, misinterpretation of wayside signal indications, or incapacitation of the crew. Pursuant to orders of the Interstate Commerce Commission (ICC),[1] cab signal systems, automatic train control and automatic train stop systems were deployed on a significant portion of the national rail system to supplement and enforce the indications of wayside signals. However, these systems were expensive to install and maintain, and with the decline of intercity passenger service following the Second World War, the ICC allowed many of these systems to be discontinued. During this period railroads were heavily regulated with respect to rates and service responsibilities. The development of the Interstate Highway System and other factors led to reductions in the railroads' revenues without regulatory relief, leading to bankruptcies and eventual abandonment of many rail lines. During this period,

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[1] The ICC's safety regulatory activities were transferred to the Federal Railroad Administration (FRA) when the FRA was established in 1967.

railroad managers focused on survival, and investments in expensive relay-based train control technology were economically out of reach. Meanwhile, National Transportation Safety Board investigations of train collisions led to recommendations for implementation of collision avoidance systems.

Enactment of the Staggers Rail Act of 1980 signaled a shift in public policy that permitted the railroads to shed unprofitable lines, largely replace published "tariffs" with appropriately priced contract rates, and generally respond to marketplace realities, which increasingly demanded flexible service options responsive to customer needs. The advent of microprocessor-based electronic control systems and digital data radio technology during the mid-1980s led the freight railroad industry, through the Association of American Railroads (AAR) and the Railway Association of Canada, to explore the development of Advanced Train Control Systems (ATCS). With broad participation by suppliers, railroads and the FRA, detailed specifications were developed for a multi-level "open" architecture that would permit participation by many suppliers while ensuring that systems deployed on various railroads would work in harmony as trains crossed corporate boundaries. ATCS was intended to serve a variety of business purposes, in addition to enhancing the safety of train operations.

Pilot versions of ATCS and a similar system known as Advanced Railroad Electronic Systems (ARES) were tested successfully, but the systems were never deployed on a wide scale. However, sub-elements of these systems are employed for various purposes, particularly for replacement of pole lines associated with signal systems.

Collisions, derailments, and incursions into work zones used by roadway workers continued as a result of the absence of effective enforcement systems designed to compensate for effects of fatigue and other human factors. Renewed emphasis on rules compliance and Federal regulatory initiatives, including rules for control of alcohol and drug use in railroad operations, requirements for qualification and certification of locomotive engineers, and negotiated rules for roadway worker protection led to some reduction in risk, but tragic loss of life and property continued to occur.

Over the past decade and a half, the railroad safety record has improved significantly while the railroads handled considerably more traffic. Nevertheless, on the Nation's rail systems an annual average of 7 fatalities, 55 injuries, and $20,631,111 in property damage occurs that could be prevented by PTC-type systems.[2] The implementation of other pending rule changes and industry actions could play a role in further reducing these numbers. At the same time, traffic and system density are expected to continue to grow, and the extent to which these factors interact has not been clearly resolved.

In 1994, the FRA reported to the Congress on this problem, calling for implementation of an action plan to deploy PTC systems (*Railroad Communications and Train Control*, July 1994). The report forecast substantial benefits of advanced train control technology to support a variety of business and safety purposes, but noted that an immediate regulatory mandate for PTC could

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[2]Conservative estimates based upon prevention of events addressed by "Level 3" systems, as described in this report (not including events evaluated as questionable).

not be currently justified based upon normal cost-benefit principals relying on direct safety benefits. The report outlined an aggressive Action Plan implementing a public/private sector partnership to explore technology potential, deploy systems for demonstration, and structure a regulatory framework to support emerging PTC initiatives.

Following through on the Report, the FRA committed approximately $40 million through the Next Generation High Speed Rail Program and the Research and Development Program to support development, testing and deployment of PTC prototype systems in the Pacific Northwest, Michigan, Illinois, Alaska, and the Eastern railroads' on-board electronic platform. As called for in the Action Plan, the FRA also initiated a comprehensive effort to structure an appropriate regulatory framework for facilitating PTC and for evaluating future safety needs and opportunities.

In September of 1997, the Federal Railroad Administrator asked the Railroad Safety Advisory Committee to address the issue of Positive Train Control. A Working Group was established, comprised of representatives of labor organizations, suppliers, passenger and freight railroads, and interested State departments of transportation. The Working Group was supported by the FRA counsel and staff, analysts from the Volpe National Transportation Systems Center, and advisors from the NTSB staff. The Working Group decided to operate through a Standards Task Force and a Data and Implementation Task Force (which had primary responsibility for drafting this document). This report is a consensus product of the Working Group, which is continuing its efforts.

As this work has gone forward, other collaborative efforts, including development of Passenger Equipment Safety Standards (including private standards through the American Public Transit Association), Passenger Train Emergency Preparedness rules, and proposals for improving locomotive crashworthiness (including improved fuel tank standards) have targeted reduction in collision/derailment consequences.

What is PTC?

The Working Group began its efforts by defining PTC core features as follows:

a. Prevent train-to-train collisions (positive train separation).

b. Enforce speed restrictions, including civil engineering restrictions (curves, bridges, etc.) and temporary slow orders.

c. Provide protection for roadway workers and their equipment operating under specific authorities.

The Working Group identified additional safety functions that might be included in some PTC architectures:

- Provide warning of on-track equipment operating outside the limits of authority.

- Receive and act upon hazard information–when available–in a more timely and/or more secure manner (e.g., compromised bridge integrity, wayside detector data).

- Future capability: Generate data for transfer to highway users to enhance warning at highway-rail crossings.

The Working Group stresses that efforts to enhance highway-rail crossing safety must recognize the train's necessary right of way at grade crossings. In addition, it is important that warning systems employed at highway-rail crossings be highly reliable and "failsafe" in their design.

Principal Findings

1. Effective PTC systems can prevent certain types of collisions and derailments. The Working Group's Accident Review Team analyzed thousands of accident/incident records and concluded that, depending upon the sophistication of the PTC system, approximately 40 to 60 main line collisions and derailments, including train incursions into authorized work zones, could be prevented by PTC each year. Because average train densities are rising as service increases, there is reason to believe that PTC may be needed even more in the future to protect the safety of railroad operations.

2. With adequate investment and proper planning, PTC systems can be built to serve the needs of the general freight rail system and intercity and commuter passenger railroads. The railroads have invested tens of millions of dollars in developing and demonstrating pilot versions of PTC systems, and they remain convinced that contemporary electronic technology provides an opportunity to develop more advanced forms of train control. The international signal and train control, telecommunications, and other supply communities are offering a variety of PTC products for future applications.

3. Although PTC systems configured for the general rail system are not available currently "off-the-shelf," planning and development are underway to produce such systems. PTC systems configured to be affordable for the bulk of the national rail system will likely utilize–

   - the Global Positioning System (GPS) with differential augmentation as the foundation, but not sole input, of its train location system,

   - data-link radio as a principal communications medium between trains and controlling computers,

   - on-board computers to prevent train-to-train collisions, enforce speed limits, and protect roadway workers, and

   - wayside interface units to relay information available in the field to controlling computers, among other features.

Most of the hardware and some of the software associated with these elements is already available, and some of it is being implemented in the railroad industry on a piecemeal basis for other purposes. Testing has shown that basic PTC safety functions can be successfully and practically executed in the field. However, planning for PTC system integration is not complete. The most complex software is yet to be written in a form that could be readily applied to a variety of route systems and easily interfaced with related systems such as dispatch center computers, existing signal systems, and the like. The Working Group is confident that these additional challenges can be met, but cautions that each stage of development must be completed in sequence. Adequate validation and verification of software systems, and proper training of system operators will ensure that additional risks introduced with the system are addressed.

4. PTC systems must be interoperable if safety benefits are to be realized and costs are to be contained. Interoperability (defined in this report as relating to the ability of trains to move from one railroad to another under the control of the host railroad's PTC system) will be critical because extensive track rights arrangements and joint terminal operations cause lead locomotives from several railroads to be intermingled on the same lines. Under increasingly common "power sharing" arrangements, entire trains transit the lines of two or more railroads from origin to destination without changing locomotives. In theory, PTC systems can be designed to provide interoperability among many systems with widely disparate architectures. However, such an approach would result in heavy reliance on very complex software and the necessity for each locomotive to carry in its on-board computer hardware and software for a variety of systems. The Working Group noted that–for PTC systems–complexity and variety are the enemy of economy and availability.

5. Interoperability can be achieved with compatible architectures that incorporate different levels of functionality. Railroads will need flexibility to deploy systems that meet their service needs without unnecessary expense.

6. PTC development efforts now underway have the potential to produce interoperable, effective technology. The Illinois project described in this report, which includes participation by the State of Illinois, the FRA and the Association of American Railroads, is serving as the venue for developing interoperability standards for PTC, for which completion is expected later this year. That same project is the only current effort by the railroads to develop a form of PTC that could replace existing methods of train operation and increase capacity on existing rail lines (through "flexible blocks" that reflect the current position and speed of the train rather than pre-established segmenting of the line between fixed signals). The Communication Based Train Management System (CBTM) being developed by CSX Transportation, and the Alaska Railroad's PTC effort, provide promising approaches directed at non-signalized territory, and the Michigan high-speed project seeks to demonstrate the practicability of using the existing signal system as a foundation for a PTC system. Yet these disparate systems need to reconciled with respect to interoperability if they are to fulfill their potential, based upon the new industry standards promised this year.

7. Estimated costs for implementation of very capable PTC systems are now higher than the Association of American Railroads provided estimates for FRA's 1994 report. An Economic

Team formed from members of the Working Group's Data and Implementation Task Force estimated cost ranges for installation of PTC on the Nation's rail lines. The team first estimated unit costs of accident items, settling on willingness to pay to avoid figures of $2,700,000 per fatality, and $100,000 per injury, except in passenger service, where an injury was estimated to cost $55,000. Further, the team looked at real company figures from a Class 1 freight railroad, and determined that reported damage to track and equipment accurately represented societal costs. There were several other factors analyzed, but the overwhelming bulk of potential benefits would come from those avoiding fatalities, injuries and damage to railroad property.

The team next analyzed the costs of components of PTC systems, using real world experience of team members as a guide, and passing the results on to a supplier for further scrutiny and comment. The team then applied its estimates to the five largest (now four) Class 1 railroads, which at the time included Conrail. That does not imply that the team thought it would be wise to apply PTC to the entire systems of those railroads. There probably are deployment strategies which would be much more cost-effective. The team found that it would cost about $1,200,000,000 to equip all of the lines of those railroads with a level 1 type PTC system (addresses "core" PTC functions only), and about $7,800,000,000 to equip all of their lines with a level 4 type PTC system (increased functionality addresses additional safety monitoring systems and enhanced traffic management capabilities). These costs are total discounted life cycle costs, including procurement, installation and maintenance, over 20 years.

The team then compared the costs of applying PTC to the benefits, again using the five largest Class 1 freight railroads, including Conrail. The 20 year total discounted benefits ranged from about $500,000,000 for a level 1 PTC system, to about $850,000,000 for a level 4 PTC system. When the costs are compared to the benefits, it is clear that PTC would become cost-effective only if the costs were to decrease because of technological improvement, if the efficiency would be increased because of a more selective deployment, if the willingness to pay to avoid a fatality were to increase, or if PTC were to become a necessary condition for implementing productivity improvements, or if some combination of these were to occur.

8. <u>Because of the costs involved and the time required to complete development of PTC systems that could fully control train movements, less ambitious approaches merit examination</u>. The history of efforts to develop complex computer-based technology suggest that unanticipated difficulties can arise and require additional time to adjust and "de-bug" the software. Further, the date by which fully capable PTC may be available at an affordable cost is not clearly determined. Accordingly, several railroads have conceived of systems addressing the PTC core functions that rely more heavily (or exclusively) on on-board equipment. These systems, which the Economic Team estimated could be deployed for as little as $591 million (initial costs), deserve full evaluation because of their potential for early implementation.

Issues for which the Working Group was unable to make findings as this report was finalized included the extent to which risk of PTC-preventable events by line segment characteristics (e.g., traffic density, switches, curvature, etc) can be forecasted to help target investments in safety systems. The Working Group has served as a peer review body for development by the Volpe National Transportation Systems Center of a Corridor Risk Assessment Model. This effort seeks to analyze risk using a geographic information system platform and statistical tools. Working Group contributions have led to substantial revisions in the study methodology, and as this report was submitted the Working Group was beginning to review the results of the modeling effort. In addition, the Volpe Center was conducting a validation test using data for preventable events for a two-year period subsequent to the study period.

Conclusions and Recommendations

The RSAC notes with approval encouraging advances in the use of train control technology for safety. As early as October of 1999, Amtrak will implement an advanced civil speed enforcement system (ACSES) on the Northeast Corridor (NEC) from New Haven to Boston; and shortly thereafter, New Jersey Transit Rail Operations (NJT) will implement a compatible technology on its lines. In combination with the cab signal/automatic train control system already in place on the NEC, these systems are expected to provide interoperable PTC core features on the entire NEC, as well as on NJT lines, in the future.

Developments on the NEC will help build confidence in PTC technology, but the systems involved are not directly transferable to the needs of freight and passenger operations outside of electrified territory (where, in general, there is no existing cab signal system on which to build). Nevertheless, progress toward resolution of technical issues related to deployment of PTC systems across the breadth of the freight railroad network is also underway. The Union Pacific/Burlington Northern Santa Fe “PTS” project showed once again that train braking distances can be successfully calculated on-board and that GPS/DGPS positioning can provide the foundation of a successful train location system in multiple-track territory. That project also illustrated the use of data from an existing traffic control system as an element of an “overlay” type PTC architecture. The Alaska Railroad PTC project will yield further confidence that PTC can be implemented in non-signal territory with excellent results.

Much remains to be done. The PTC Working Group concluded PTC systems can be successfully deployed if they are affordable and if appropriate care is taken in their design, testing and deployment. The primary obstacle is cost. Although estimates of system costs have increased substantially since the FRA last sought data on this issue in 1994, there are persuasive reasons to believe that costs will become manageable in the future:

- The cost of consumer and industrial electronic systems continues to fall in relation to the value of products.

- Price quotations for PTC applications are likely to be reduced in larger quantities.

- Railroads are currently making investments in more capable computer-aided dispatching systems that incorporate sophisticated traffic planners. These and other investments are necessary to realize the benefits of more capable PTC systems, such as those that may offer capacity enhancements through “flexible-block” management of train separation.

- Locomotive manufacturers, supported by the AAR, are working toward more capable and better-integrated cab electronics. Items that are necessary PTC system components, such as

GPS/DGPS receivers, electronic display screens, and electronic control of brakes and throttle, are already being offered as basic equipment on new locomotives.

- The Illinois Project provides a venue for joint systems development that, if it is sufficiently sophisticated and modular in design, may provide the foundation for successful applications on freight railroads and passenger railroads operating outside of electrified territory, greatly reducing the cost of system development on other properties.

- Successful integration of the eastern railroads' "common bus" concept could support interoperability of systems, if adequate standards are in place.

- Innovative ideas for on-board systems that could simplify the achievement of certain PTC functions may offer promise to bridge the gap between today and full PTC implementation, if the electronic systems are forward-compatible with future technologies.

- The rapid growth of other electronic systems will create new opportunities for synergistic applications of PTC, such as providing a data network that can monitor, in real time, the health and status of cars, car components, and commodities (especially hazardous materials).

Without question, a partnership effort involving public and private sector participants is required to bring about the successful implementation of PTC systems. The Working Group makes the following recommendations to support deployment of PTC technology by creating a favorable climate and by systematically resolving technical and institutional barriers to implementation:[3]

To the Department of Transportation and the Federal Railroad Administration:

1. Complete the Nationwide Differential GPS network with redundant coverage throughout the continental U.S., including Alaska, providing a uniform and consistent position determination, velocity, and timing system for PTC and other Intelligent Transportation Systems.

   Status: Completion expected no later than 2003.

2. Continue support for retention and review of radio frequency spectrum allocations sufficient to support PTC and other necessary railroad communications services.

   Status: The Federal Communications Commission spectrum "refarming" decisions were favorable; the AAR is further reviewing spectrum needs.

3. Work to ensure that appropriate resources and investments are available to implement PTC technology that will support the safety and viability of rail passenger service, emphasizing the choice of interoperable systems that can hold down public and private sector costs

[3]FRA staff members have participated in the development of this report. However, since development of policy within the Executive Branch of the United States Government requires coordination and clearance not feasible within the time available for preparation of this report, conclusions and recommendations related to Federal action should be viewed as the opinions of the non-Federal members of the RSAC.

Status: Funding provided thus far includes Illinois and Michigan high-speed PTC, support for ACSES system through Amtrak capital budget. The FRA is working with the FTA and commuter authorities regarding future plans.

4. Maximize investment opportunities under TEA-21 to support deployment of the Railroad Infrastructure Financing program, which, with $3.5 billion in authority, represents an excellent opportunity to provide capital for these investments.

   Status: DOT has stated that it is implementing TEA-21 with the maximum emphasis on intermodal funding approaches. The NPRM to implement the RRIF program was published on May 20, 1999.

5. Through RSAC–

   a) Evaluate results of the Corridor Risk Assessment Model to determine if the distribution of risk on the rail system offers notable opportunities for collision and derailment prevention by focusing initial PTC installations on certain rail corridors (ongoing).

   b) Further evaluate benefits and costs of PTC on business-scale corridors (begin 3rd quarter 1999).

   c) Develop human factors analysis methodology to project the response of crews and dispatchers to changes brought about by "overlay" type PTC technology, including possible "reliance" or "complacency" and "distraction" effects (initiated 2nd quarter 1999). Apply methodology to candidate projects.

   d) Develop guidelines for standard operating rules applicable to various forms of PTC systems, with particular attention to issues regarding unequipped trains and trains with failed on-board equipment (begin 3rd quarter 1999).[4]

   e) Complete development of proposed performance-based standards for processor-based train control systems (ongoing).

   f) Produce a risk measurement toolset for a safety-critical assessment process (ongoing).

   g) Using available analytical tools, evaluate the safety merits of candidate systems.

6. With the railroads and other interested parties, continue to work with the Intelligent Transportation System (ITS) program to ensure that standards are developed for ITS User Service #30, Highway-Rail Intersections, including appropriate interfaces and messages (e.g., train locations, directions, speed, grade crossing occupancy) between PTC and Intelligent Transportation Systems.

[4] References to trains in this document are, in most cases, inclusive of locomotives and other on-track equipment including roadway maintenance machines, hi-rail vehicles, and other equipment which routinely occupy track under authority of mandatory directives or operating rules.

Status: Initial standards development workshop Arlington, VA, July 22 and 23, 1999.

7. Through the Federal Highway Administration and ITS America, foster deployment of in-vehicle systems capable of appropriately utilizing data provided through PTC or other systems to warn motor vehicle drivers of the need to yield to trains at highway-rail grade crossings.

   Status: Ongoing.

8. Promote prudent research and development to enhance the potential for ITS and allied technologies to advance safety at highway-rail grade crossings by other means. For example, remote monitoring systems could warn train control centers and/or traffic management centers of highway vehicles fouling the crossing and/or failures of active warning system equipment.

   Status: Ongoing.

To the Association of American Railroads:

9. Complete standards for PTC interoperability in 1999.

   Status: Workshops underway.

To the AAR, State of Illinois and the FRA:

10. Through the Illinois project–

    a) Develop and deploy a PTC system adequate to support high-speed passenger service and freight operations with flexible block technology.

    b) Ensure that the PTC system is modular in design so that it can used to support the safety of railroad operations on other corridors.

    c) Ensure that decisions on technology applications and interoperability in the Illinois project will facilitate decisions by passenger rail systems regarding investment in compatible technology.

    d) Coordinate with the eastern railroads' project for development of a "common bus" and the locomotive manufacturers' efforts to provide integrated on-board electronics platforms to maximize the likelihood that interoperability will be achieved at an affordable cost and at an early date.

The Working Group appreciates the support provided by member organizations and recommends that its tasks (RSAC No. 97-4, 97-5, and 97-6) be continued consistent with Recommendation 5 above, with the expectation that the Working Group will make further reports and recommendations necessary to achieve its mission, including proposed performance standards for PTC systems.

I. Introduction

This is a report of the Railroad Safety Advisory Committee (RSAC) to the Federal Railroad Administrator on the status and future of Positive Train Control (PTC) systems. The report was prepared by the RSAC PTC Working Group, which worked for over a year to gather facts, review options, and deliberate on the best approach to encouraging rapid and successful deployment of PTC technology. The working group was comprised of representatives of freight and passenger railroads, labor organizations, industry equipment suppliers and State departments of transportation, assisted by Federal Railroad Administration (FRA) counsel and staff. The implementation of PTC systems is a broad and complex subject. As such, the working group has not yet been able to specifically address all issues related to deployment of PTC, although the group was able to advance understanding of the issues.

In addition, the working group identified important actions that should be taken to create a favorable climate for introduction of PTC systems. The RSAC requests that the full text of this report be included in the Secretary of Transportation's forthcoming progress report to the Congress on PTC systems.

Since the early 1980s, the railroad industry has recognized the possibility of using data radio communications, emerging microprocessor-based systems, and other contemporary technologies to perform enhanced train control functions. In concept, this approach should make it possible to end most train-to-train collisions, enforce restrictions on train speed, and enhance protection for roadway workers–at a cost lower than would be expected using traditional approaches. Some in the industry have identified business benefits that might accrue from institution of such systems. All parties involved in the RSAC PTC process seek to define systems that are safety-effective, cost-effective, and interoperable as a railroad industry standard. These are the key elements in ensuring that promised benefits of the technology are achieved in actual deployments.
Industry standards efforts and test programs have developed several variations of this concept, but railroads have not yet judged it technically or financially prudent to make the largescale capital investments required to complete systems development and to widely deploy the technology. Meanwhile, the National Transportation Safety Board (NTSB) and the FRA have continued to urge that the potential safety benefits of PTC be realized at the earliest possible date.
One of the difficulties in realizing the benefits of PTC systems is the number of entities that need to cooperate to make it happen. With the goal of encouraging collaboration between the public and private sectors and gathering information to enlighten public policy, Administrator Molitoris requested that the RSAC investigate this issue and recommend appropriate action. On September 30, 1997 the RSAC accepted three PTC-related tasks. In summary, the tasks were to:

- Prepare a descriptive report to facilitate understanding of current PTC technologies, definitions, and capabilities (Task 97-4) ;

- Complete analysis and prepare recommendations to address any remaining issues regarding the feasibility of implementing fully integrated PTC systems, evaluate factors that may guide decisions on how PTC could yield optimum benefits in relation to costs, and determine the timetable over which such systems could be deployed–taking into account the need to first complete testing and revenue demonstration of any new system (Task 97-5); and

- Facilitate implementation of software-based signal and operating systems by discussing potential revisions to the Rules, Standards and Instructions (49 CFR Part 236) to address processor-based technology and communication-based operating architectures, including consideration of disarrangement of microprocessor-based interlockings, performance standards for PTC systems at various levels of functionality (safety-related capabilities), and procedures for introduction and validation of new systems (Task 97-6).

The results of the first two tasks are reflected in the body of this report. The third task–preparation of performance standards for processor-based signal and train control technology–is well underway. The report also describes the PTC Working Group's efforts to draft proposed regulations that will be technologically neutral and will facilitate the onset of PTC deployment by creating a higher degree of predictability regarding the manner in which regulatory approval will be achieved.

This report was not written to answer one of the most urgent questions regarding PTC – i.e., whether the FRA should mandate the institution of PTC functions on any significant portion of the Nation's rail lines. In January of 1998, the Board of Directors of the Association of American Railroads (AAR) accepted a challenge from Secretary of Transportation Rodney Slater and Administrator Molitoris to enter into a partnership for PTC systems development. The venue for this effort is a project initially funded by FRA under section 1010 of the Intermodal Transportation Efficiency Act of 1991 (now section 1103(3)(2) of the Transportation Equity Act for the 21st Century) on the designated high-speed passenger rail line between Chicago, Illinois, and St. Louis, Missouri. The project unites the State of Illinois, the FRA, and the Class I railroads through the AAR (including the Union Pacific Railroad as owner of the line and Amtrak as the passenger train operator) in seeking development of a PTC system that can support high-speed passenger operations as well as conventional freight service with a high degree of safety and efficiency. The standards developed as a part of this project will be available for use with PTC developments on other rail lines. Funding is provided by the FRA, Illinois Department of Transportation (IDOT), and the AAR.

The first product of the Illinois Project, expected to be completed within this calendar year, will be industry standards for interoperability of PTC systems. Interoperability (which is more precisely described herein) refers to the ability of lead locomotives from one railroad to respond to the control of another railroad's PTC system while traversing that railroad's lines. Since shared power arrangements and various types of joint operations are becoming more widespread rather than the exception in contemporary railroading, interoperability is important to realizing the safety and other benefits of PTC.

In addition to writing rules for the performance of PTC systems, the PTC Working Group will remain active over the next year (and perhaps beyond) to track the progress of the Illinois Project and other PTC efforts and to act as a broad-based advisory panel in support of these activities. The working group will report to the FRA Administrator regarding the progress toward PTC implementation and any actions needed to facilitate system deployment.

Making these investments attractive to freight and passenger railroads requires that PTC technology be shown to be reliable and capable of addressing customer needs in a more efficient manner than would be the case using alternative technology. The working group is hopeful that the Illinois Project and other technology development efforts underway on major railroads will provide the confidence needed to support, first, large-scale revenue demonstration of the technology and, second, wider application of these technologies on the core of the national rail system.

Over the past year of deliberations, the PTC Working Group has come to appreciate that deployment of PTC involves significant technical challenges and will require a predictable and progressive public policy environment. PTC systems will not be deployed at an early date unless all responsible parties play a constructive role in advancing the technology and removing technical, economic, and institutional barriers. The executive summary of the report addresses conclusions and recommendations that can provide the most favorable climate for development and deployment of PTC systems. Since development of policy within the Executive Branch of the United States Government requires coordination and clearance not feasible within the time available for preparation of this report, conclusions and recommendations related to Federal action should be viewed as the opinions of the non-Federal members of the RSAC. There will be materials published subsequently by the Department of Transportation, specifically identifying recommended Federal actions.

Safety is the primary focus of this effort. The NTSB has long advocated the implementation of systems that can provide positive train separation. The *"NTSB Most Wanted List of Transportation Safety Improvements"* includes the following recommendation: "Require a railroad collision avoidance system."

The 1994 Report to Congress concluded that the various attributes of PTC would improve railroad safety and enable improved management of train operations in a variety of ways and at lower cost than conventional train control systems. Subsequently, the FRA created a PTC working group within the RSAC that defined three core functions of PTC. These core functions would:

- Prevent train-to-train collisions (positive train separation).
- Enforce speed restrictions, including civil engineering restrictions and temporary slow orders.
- Provide protection for roadway workers and their equipment operating under specific authorities.

II. The Role of Current and Forecasted Railroad Traffic to National Transportation

The railroads play a critical and growing role in moving our Nation's freight, i.e.,39 percent of the intercity traffic measured by weight and distance (ton-miles) is moved by rail, compared to 29 percent on trucks.[1] Since the early 1980s, the railroads have increased their traffic (tons) by 25 percent, while their network (miles of road owned) declined by 34 percent.[2] This resulted in increased traffic density by concentrating traffic over a smaller network. In the last few years, the railroads have expanded capacity by double-tracking track, such as CSXT has done in Ohio (or even triple or quad tracking, in some cases), and opening previously closed routes, such as the BNSF's repurchase and reopening of the Stampede Pass line in Washington state. Positive train control is a way of further increasing capacity to accommodate traffic growth with the existing track infrastructure.

Rail traffic measured in revenue ton-miles has grown by 35 percent during the ten year period 1988-97.[3] In 1997, the railroads originated 25 million carloads of traffic. The following commodities account for 73 percent of the total carloads originated: intermodal (trailers and containers on flatcars) (7.2 million carloads), coal (6.7 million carloads), chemicals (1.7 million carloads), motor vehicles and equipment (1.4 million carloads), and grain (including soybeans) (1.2 million carloads).[4] Commuter rail ridership has grown by 14.9 percent during the ten year period 1987 to 97 and by 37.9 percent in the last fifteen years.

The Nation's commuter rail operators currently carry over 1.2 million passenger trips a day and in some cities such as Chicago and New York, they are carrying a significant share of the commuters traveling to jobs in the central city. In Chicago the 1990 census reported that Metra carried 21 percent of the work trips to the downtown area and in the New York region commuter rail operators served 78.8 percent of the Manhattan-bound work trips from Fairfield County, Connecticut, 67.9 percent of the trips from Long Island, and 70 percent of the trips from Mercer County, New Jersey.

Impact of Forecasted Rail Traffic to National Transportation

The Nation's highways are already congested. The Federal Highway Administration reports in its "1997 Status of the Nation's Surface Transportation System: Condition and Performance, Report to Congress" that 52 percent of the urban interstate highways were congested in 1995.[5] Rail intermodal traffic is the fastest growing segment of railroad traffic and is forecasted by Standard & Poor's DRI to increase by nearly 5 percent per year between 1997 and 2003, an increase of nearly 8,000 trailers and containers per day during the period.[6] These intermodal units are carried long distances, the average length of haul exceeding 1,400 miles.[7] In a worst-case scenario, in which no more intermodal traffic could be moved in 2003 than in 1997 because of railroad

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[1] Eno Foundation, "Transportation In America: 1998," p. 44.
[2] Association of American Railroads, "Railroad Facts: 1998 Edition (1997 data)," p. 28, 44.
[3] Ibid, p. 27.
[4] Association of American Railroads, "Analysis of Class I Railroads: 1997," p. 24.
[5] Association of American Railroads "Weekly Railroad Traffic."
[6] Memo to 1993 Commodity Flow Survey data users on shipments of hazardous materials, Table 1.
[7] STB "1996 Carload Waybill Sample" processed by FRA.

capacity constraints, this traffic would be shifted to highway, increasing vehicle miles traveled (VMTt) in 2003 by 4 billion. This traffic would be in addition to combination trucks' 68 billion vmt (up from 55 billion vmt in 1995 on urban and rural interstates[8] based on forecasts by Standard and Poor's DRI of motor carrier volume growth[9]). Congestion would increase because lane miles of interstate highway capacity are expected to increase only minimally during this time period.

Additional vehicle miles traveled on the interstate system due to lack of railroad capacity would also increase highway accidents. Based on National Highway Traffic Safety Administration accident frequency statistics, highway accidents involving large trucks would increase by 107 fatalities and 2,096 injuries.[10]

Importance of Current Railroad Traffic to National Transportation

Currently, the railroads carry roughly 170,000 trailers and containers per week or over 24,000 per day.[11] If the railroads, for capacity reasons, could not carry this intermodal traffic, a significant commitment would be required of the approximately 1.7 million heavy trucks (class 8) just to move this freight.

The railroads are significant intercity carriers of hazardous materials. The Bureau of The Census and United States Department of Transportation "1993 Commodity Flow Survey" found that railroads hauled 45 percent of the combined highway and rail intercity ton-miles of hazardous shipments.[12] The Surface Transportation's Board's "Carload Waybill Sample" as summarized by the FRA indicates that 94 million tons of hazardous materials were moved by rail in 1996, thereby keeping a substantial amount of this commodity off the highways. In particular, there were an estimated 889,000 tank car shipments traveling an average of over 700 miles per shipment. Three or four tank trucks would be needed to substitute for each of these rail shipments. Specialized tank trucks, however, are not commonly available.

Plastics manufacturing depends on chlorine, one of the most rail-dependent chemicals, because of safety requirements. More than 75 percent of all chlorine shipped in the country is handled by rail. The remainder moves by barge, which is very slow, and by small pressurized tank trucks, which are not available in adequate supply for moving large quantities of chlorine. Polypropylene and polyethylene, used in the production of plastic containers, move over 75 percent by rail-covered hopper cars. These products are too voluminous (nearly 170,000 carloads in 1996) to move by truck.[13] In addition, transloading the product from railcar storage to truck raises the possibility of product contamination due to multiple handling. Another commodity,

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[8] STB, "1996 Carload Waybill Sample" processed by FRA.
[9] U.S. Department of Agriculture, "Transportation of U.S. Grains: A Modal Share Analysis, 1978-95," March 1998.
[10] National Highway Traffic Safety Administration, "Traffic Safety Facts of 1996," Table 3, p. 17
[11] Standard and Poor's DRI "North American Transportation Quarterly," Third Quarter 1998, p. 18.
[12] STB "1996 Carload Waybill Sample" processed by FRA.
[13] Federal Highway Administration, "1997 Status of the Nation's Surface Transportation System: Condition and Performance, Report to Congress," Exh. 3-7, p. 18.

ethylene oxide, used in the manufacture of numerous products, from solvents to plastic wrap, moves nearly entirely by rail.

Phosphate rock, potash, and other raw materials used to produce fertilizers are largely transported by rail, and over 35 percent of fertilizer and agricultural chemicals products are also moved by rail. Although some raw materials and finished goods move relatively short distances to local mixing plants that might be accommodated by truck, and while barges handle a considerable share of the Mississippi River traffic after the initial move from Florida mines or processing plants, the volumes shipped by rail are so large that substitution of another mode would be difficult and expensive. In addition, one key input in fertilizer production, nitric acid, is nearly 100 percent carried by rail into production plants.

The railroads are relied upon heavily to move the majority of the Nation's coal shipments. Railroads handle 55 to 60 percent of total United States coal production, and large segments of the coal mining industry use the railroads to deliver coal to power plants, steel mills, and other industrial customers, or for delivery to river and ocean ports for movement by water to domestic and overseas destinations. Many Appalachian mines are inaccessible by truck or other alternate transport service. The large volumes of coal could strain the capacity of the coal truck fleet as well as the road network and unloading facilities at the point of consumption. The even greater volumes and longer distances involved in many coal movements from western mines would make substitution of truck service impractical.

The motor vehicles and parts industry relies heavily on rail service for both inbound parts and outbound assembled vehicles. The availability of customized rail service permits auto manufacturers to hold only a few days supply of parts inventory. In addition, the railroads play a major role in the transport of assembled autos to distribution points for local delivery to auto dealers. In 1996, the railroads moved more than 1 million rack cars, shipments of assembled motor vehicles, or more than 80 percent of this traffic. The railroads also moved over 400,000 carloads of motor vehicle parts. Each of these commodities moved nearly 1,000 miles on the average.[14]

In the paper, pulp, and allied products industry, high proportions of pulp and paper mills' raw materials and finished goods move by rail. Shipments of key raw materials, such as wood pulp, clay, caustic soda, lime, and sulfuric acid rely heavily on rail and are too voluminous to move by truck. Other modes of transport are not price-competitive with rail for moving pulp from the southeastern United States to paper mills in Wisconsin and Michigan. In addition, the older mills do not have loading facilities suitable to receive pulp by truck. Rail is also used for moving pulpboard from paper mills to the converting plants where corrugated shipping containers and folding cartons are produced, because trucks are not a cost-effective substitute.

Glass manufacturers are extremely dependent on rail service, because they require soda ash, produced primarily in Wyoming and California at facilities that ship entirely by rail (or by

[14] Standard and Poor's DRI "US Freight Transportation Forecast...to 2006," Fig. 9, p. 10.

short-distance truck to rail). Manufacturers cannot practically store substantial amounts of soda ash, because precautions are needed to prevent its contamination.

USDA reports that in 1995 rail moved 66.1 percent of wheat tonnage and 36.5 percent of corn tonnage. Overall, rail moved 40.0 percent or 152 million tons of all United States grains (and soybeans), or nearly the same amount of grain moved by truck in 1995 (155 million tons).[15] Although many grain movements can be handled by truck, or by truck in combination with barge, the truck fleet is not large enough to accommodate all rail-borne traffic. The beverage sector relies heavily on rail for the delivery of sugar, high fructose corn syrup, and other important raw materials.

In the copper mining industry, rail carries roughly two-thirds of the shipments of concentrated copper ore to refiners and smelters. The production of iron ore pellets in the Upper Peninsula of Michigan relies on rail for receiving bentonite clay, an essential additive, from Wyoming. Much of the iron ore moves to Lake Michigan and Lake Superior by rail for water delivery to steel mills located on Lake Michigan and Lake Erie. A large quantity moves by rail to landlocked steel mills.

Truck Driver Shortage

The president of the ATA, Walter McCormick, Jr. recently stated that "the trucking industry has identified the lack of trained drivers as its top concern..."[16] If growth in rail intermodal traffic could not be accommodated by the railroads and moved to the highway, the shortage of truck drivers would worsen, because of the unattractiveness of long distance driving to truck drivers.

Commuter Operations

The growth of commuter service over existing freight lines increases the competition for existing railroad capacity. This is a contentious issue; commuter operators are negotiating for longer hours of operation to attract additional rail commuters, while the freight railroads are trying to minimize the interruptions to their growing freight train service. Positive train control could provide increased capacity and safety allowing these two rail functions to use the same tracks, through more efficient dispatching and assured physical separation. Commuter operations were recently started in Dallas and other cities are planning new service. In Los Angeles and Washington, DC, growth in both freight and commuter service has led to capacity concerns. PTC could provide for major expansions in commuter rail, because neither the freight railroads nor the commuter operations in their negotiations are willing to make the investments to provide the additional capacity needed.

[15] National Highway Traffic Safety Administration, "Traffic Safety Facts 1996," Table 3, p. 17.

[16] Traffic World," Nov. 16, 1998, p. 42.

Commuter rail, using locomotives or electric or diesel powered self-propelled equipment, has proven to be an efficient and effective way to get commuters to work destinations in traditional central cities and, increasingly, to suburban work locations. Commuter rail has been the fastest growing segment of the public transit industry and the rapid growth in ridership reflects the establishment of new systems, the expansion of ridership on the older passenger rail systems, and new expansion into the suburban passenger rail market. An example of this new market can be seen in Los Angeles where Metrolink recently opened the new Riverside line that provides service between Riverside and Orange Counties and does not go downtown. Today the Nation's 16 commuter rail systems operate over 4,200 scheduled trains each weekday.

Since 1996 commuter rail operations have started up in Dallas (Trinity Railway Express) Texas, and Stockton (Altamont Commuter Express) California. New commuter rail operations currently under development and scheduled to open by the end of 1999 include a 20 mile commuter rail operation in Burlington, Vermont and a 40 mile operation in Seattle, Washington. In 2000, Trinity Railway Express is scheduled to open 14 additional miles of service to Ft. Worth, pushing ridership from the current 2,000 riders a day to over 8,000.

Established commuter operations are also expanding to meet ridership demand and to combat urban congestion and air quality problems:

- In Boston, two branches of the New "Old Colony Line" were opened in 1997, adding a total of 26 train trips a day from Plymouth and Middleboro serving over 13,000 daily riders, significantly exceeding estimates. Currently over 8 additional commuter rail extensions are under consideration in Boston.

- In Los Angeles, Metrolink, which began operations in 1992 with 50 trains a day carrying 2,800 passengers a day, has expanded to 128 trains carrying almost 30,000 passengers a day. Two additional extension projects are currently under study by the railroad.

- In Philadelphia, where SEPTA's commuter rail operations carry 90,000 riders a day, an investment and environmental study has been completed for a 48-mile suburb to suburb line extending from Morrisville on the east to Glenloch located west of the City.

- In New Jersey, the reactivation of commuter service is being studied on the New York and Susquehanna & Western line and on the West Shore line.

- The Long Island Railroad is currently developing the East Side Access project which will permit its trains to reach Grand Central Terminal, as well as Penn Station, an effort that will improve travel time for 30 percent of the LIRR's over 75.8 million passengers a year. This project alone is projected to generate travel time savings valued at $69.6 million dollars a year and reduce carbon monoxide emissions by 720 tons a year, nitrogen oxide by 124 tons, and volatile organic compounds by 76 tons.[17]

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[17] Fiscal Year 1999 Report on Funding Levels and Allocations for Transit Major Investments; Federal Transit Administration May 1, 1998.

- In Chicago, Metra currently has 15 system expansion projects under design or study and the Northern Indiana Commuter Transit District is studying the possible addition of its first new line since the system opened in 1908.

APTA's 1998 Fixed Guideway Report[18] identifies 123 new commuter rail projects, totaling 3,326.6 miles that are currently being proposed, planned, designed, or constructed; more than doubling the 3,162.6 miles of commuter rail service currently in operation. The Transportation Efficiency Act for the Twenty-First Century (TEA 21) authorized funding for more than 40 regional/commuter rail projects among the over 200 new start mass transit projects that are currently underway. Areas where new commuter rail systems are under development include: Atlanta, Cleveland, Detroit, Denver, Kansas City, Madison, Minneapolis, Nashville, Providence, Raleigh, Salt Lake City, and Tampa.

One of the central reasons that commuter rail is viewed as such an attractive solution to urban transportation problems is the potential opportunity to utilize freight railroad rights-of-way. It is much easier to obtain public support for these projects, and they can usually be completed at a much lower cost, when existing transportation corridors are used. Mass transit investments that expand freight railroad capacity or reactivate abandoned rail lines to permit the introduction of passenger rail service, are frequently viewed as the best investment of public transit funds.

Commuter rail services generate benefits for both the commuter and the non-commuter estimated at over $5.26 billion a year.[19] For every dollar invested in commuter rail there is an economic return of up to $6. These benefits include cost savings from reduced traffic accidents and fatalities, congestion mitigation cost savings for all commuters and reduced traffic delay costs for commuter rail riders, as well as other environmental mitigation and general cost savings. In addition, commuter rail operations across the Nation have served as an important catalyst for regional economic growth, job creation, and enhanced property values. For example, homes around transit stations are valued from 2 to 10 percent higher than comparable properties not within walking distance.

Intercity Rail Operations

Amtrak continues to progress as a managed growth program primarily using freight-owned rail lines. Substantial freight growth combined with prioritized higher speed intercity rail passenger train operations often strains the available capacity on many of the most strategic freight corridors.

Amtrak, in concert with the FRA and the State of Michigan, is continuing to show progress in the first proven communications-based Michigan High Speed Positive Train Control Project (HSPTC) in the Western Hemisphere. The technology itself is referred to as the Incremental Train Control System, or ITCS. This new, advanced technology system will provide an enhanced

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[18] Fixed Guideway Inventory; American Public Transit Association, 1998.
[19] Commuter Rail: Serving America's Emerging Suburban/Urban Economy; American Public Transit Association; September, 1997.

level of safety to train operations and protected grade crossings. Properly managed, HSPTC could enhance corridor capacity, and fuel efficiency, and significantly reduce operating schedules.

The HSPTC project is allowing Amtrak to introduce higher rail passenger train speeds, jointly with increased freight train speeds. As both average speeds are increased, the capacity and fuel efficiency of the corridor is increased, without dramatic or costly infrastructure improvements. HSPTC will dramatically enhance the operation of high speed rail passenger service while simultaneously strengthening joint freight operations.

Fuel Consumption

In the FRA's 1991 study, "Rail vs. Truck Fuel Efficiency: The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors," it was found that rail achieved higher fuel efficiency, measured by ton-miles per gallon, than trucks in all 32 scenarios. The scenarios varied by train type, such as mixed freight, TOFC, double-stack, and by varying numbers of cars. The scenarios were analyzed by using a train performance simulator and the Cummins Engine Company vehicle (truck) mission simulation model. Rail achieved from 1.4 to 9 times more ton-miles per gallon than competing truckload service.

Positive train control could generate additional fuel savings to the railroads by allowing them to improve operations and scheduling. This could reduce fuel-consuming bottlenecks in rail corridors and delays in yards. PTC, by pinpointing train locations, could permit railroads to adjust train speeds needed for going off of the main track to a siding to allow another train to pass or to make connections in yards, thereby avoiding traveling at higher than necessary speeds and unnecessary waiting.[20]

Environmental Impacts

The FRA, in its "Intercity Freight and Passenger Rail: State and Local Project Reference Guide," presented examples of the environmental benefits of intercity rail service. The FRA cited the FHWA's 1995 "Intermodal Freight Transportation," Volume 2 on the benefits of rail/truck intermodal transportation: "An efficient, coordinated long-distance truck-rail-truck intermodal movement can be up to 3.4 times more fuel efficient that a non-intermodal truck movement while emitting only 20 percent as many hydrocarbons."[21]

[20] William Carley, "Railroads Test Satellite Positioning in Effort to Improve Safety, Efficiency," Wall Street Journal Interactive Edition, June 29, 1998.
[21] Section 4, p. 1.

The Task Force of the Internal Combustion Engine Division of the Council on Engineering of the American Society of Mechanical Engineers, in its May 1992 “Statement on Surface Transportation of Intercity Freight” concluded that “there is potential for large savings in fuel consumed along with a similar reduction in engine exhaust emissions if the rail mode is used to a greater extent for movement of intercity freight.” (p. 5) This conclusion was based on their analysis using data from published studies on fuel consumption and vehicle emissions for rail and truck.

III. Methods of Operations and PTC

A. Introduction

As with all transportation systems, railroad operation requires the management of time and space. By controlling time, space can be allocated for operations. With low-density operations time is less critical, but with high speed, dense operations time becomes more critical. The evolution of various methods of train operations followed this principle. In other words, greater knowledge of location and faster communication of that knowledge is key to improving railroad capacity, efficiency, and safety. The railroad is a single degree of freedom system. The train can go either forward or in reverse, but, on single track, cannot pass, except where there are sidings. Trains traveling at greater than restricted speed[22] cannot stop within sight distance, and systems that provided for safe operation that did not rely on the operator seeing an opposing train were developed. The railroads developed rule-based systems to allow for greater speeds and to manage the allocation of space.

There are three major methods of train operations on main tracks in the United States: signal indications; mandatory directives;[23] and manual block rules. PTC systems under development are centered on one or more of these methods of operation.

1. Operations by Signal Indications

Operations by signal indications occur at interlockings, in traffic control systems, or automatic block signal systems on two main tracks arranged for movement with the current of traffic. Trains having authority to enter these systems are governed by the indications of signal aspects that are arranged to provide for movement at maximum authorized speeds; provide sufficient distance to slow a movement in approach to the point where speed is to be reduced; and provide sufficient distance to stop a movement at the point where a stop is required. Absent control devices that supplement the signal systems to enforce maximum authorized speed and speed reductions (e.g., automatic train control or automatic trainstop), compliance is dependent upon the locomotive engineer to properly control the speed of a train. With or without supplementary control devices, it is dependent upon the locomotive engineer to stop a train at a point where a stop is required.

2. Operations by Mandatory Directives

Operations by mandatory directive may occur in either automatic block signal territory or non signaled territory. Mandatory directives affect the movement of trains and other on-track

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[22] 49 CFR §236.812 Speed, restricted. A speed that will permit stopping within one-half the range of vision, but not exceeding 20 mph.

[23] 49 CFR §220.5 Mandatory Directive. Mandatory directive means any movement authority or speed restriction that affects a railroad operation.

equipment, and are identified on various railroads as train orders, track warrants, track permits, track bulletins, block authorities, and Form Ds. They provide the authority for the movement of a train and may be used for the protection of roadway workers and on-track equipment.[24]

Mandatory directives are issued verbally by the dispatcher to train crew members and/or roadway workers who must repeat the directives back to the dispatcher for verification of correctness. Mandatory directives authorize the movement of a trains and on-track equipment between specific points and provide instructions for meeting or passing other trains, speed restrictions, and other special conditions.

Where automatic block signals supplement operations by mandatory directives, indications of signal aspects furnish train crew members information about block conditions in advance and provide sufficient spacing to slow or stop a train as may be required. The dispatcher is relied upon to issue mandatory directives that provide for the safe movement of trains. It is dependent upon train crew members to comply with both the instructions contained in mandatory directives and the indications of a block signal system, and control the speed of the train and stop where a stop is required.

3. Operations by Manual Block Rules

Manual block rules are used for the movement of trains on designated portions of several railroads. In a manual block system the railroad is segmented into blocks of designated lengths. Mandatory directives are issued by a block operator or dispatcher and provide authority for a train to enter a block or blocks. No train may be permitted to enter a block occupied by a passenger train or an opposing train; a passenger train may not enter a block occupied by another train; but a freight train may follow a freight train into a block provided the following train proceeds prepared to stop in one-half the range of vision but not exceeding 20 mph. Block operators are relied upon to assure each block is unoccupied before permitting a train to enter the block. It is incumbent upon train crew members not to enter a block without authority, to properly control the speed of the train and stop where a stop is required.

4. Other Methods of Operation

For branch lines, industry tracks, other auxiliary tracks and yards, various methods of operations are employed for the movement of trains. Voice rules and yard rules are used in yard operations and switching services on industry tracks. Yard limit rules are used on main tracks extending through yards and stations and on branch lines. Timetable special instructions are utilized on branch lines, industry tracks, and in conjunction with mandatory directives on main tracks. All of these methods of operations rely upon dispatchers, operators, yardmasters, and train crew

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[24] References to trains in this document are, in most cases inclusive of locomotives and other on-track equipment including Roadway Maintenance Machines, hi-rail vehicles, and other equipment which routinely occupy track under authority of mandatory directives or operating rules.

members to be knowledgeable in the rules governing the methods of operations, issue succinct orders orally, and to comply with all the requirements.

5. Requirements for Signal and Train Control Systems

Federal regulations exist that prohibit the operation of a freight train at a speed of 50 or more mph or a passenger train at a speed of 60 or more mph unless a manual block system or a block signal system is installed and prohibits the operation of any train at 80 or more mph unless an automatic cab signal, trainstop, or train control system is installed.

An automatic block signal system or a traffic control system is required to support the installation of automatic cab signal, trainstop or train control systems. Cab signal, trainstop, and train control devices are installed on-board locomotives and, accordingly, supplement the block signal or traffic control system. Track circuits or devices along the wayside are used to communicate signal system status to the on-board equipment.

Automatic cab signals are inductively connected to track circuits and convey aspects on-board that indicate the condition of the block being traversed and the blocks in advance. No enforcement is provided by automatic cab signals and train crew members are relied upon to comply with the indications displayed, properly control the speed of the train, and stop where a stop is required.

Automatic train control devices augment automatic cab signals and only provide enforcement of speeds associated with signal indications. When a more restrictive cab signal indication is obtained, the locomotive engineer must immediately take action to reduce the train speed to that prescribed by the signal indication or the train control device will initiate a brake application to stop the train. The most restrictive cab signal indication permits a speed not exceeding 20 mph. It is dependent upon the locomotive engineer, at speeds of 20 mph or less, to stop where a stop is required.

Automatic trainstop devices also augment automatic cab signals but do not provide enforcement of speeds. When a more restrictive cab signal is obtained, the locomotive engineer must acknowledge the restrictive cab signal within a prescribed period of time or the trainstop device will initiate a brake application to stop the train. The locomotive engineer is relied upon to properly control the speed of the train after acknowledging a restrictive cab signal and to stop where a stop is required.

An automatic trainstop device may be utilized without cab signals by being intermittently inductively connected to the wayside signal system (i.e., at each signal location). When a train passes a wayside signal displaying a restricting aspect, the locomotive engineer must acknowledge the restrictive indication within a prescribed period of time or the trainstop device will initiate a brake application to stop the train. It is dependent upon the locomotive engineer to control the speed of a train after acknowledging a restricting wayside signal indication and to stop where a stop is required.

B. Current PTC System Concepts

Although the safety record of the railroads is exemplary, train collisions, overspeed derailments and accidents with roadway workers, have generated a demand from the regulators, labor and management to develop cost-effective systems that could significantly reduce the risk of these types of accidents. As a part of the RSAC process, an accident review team was established to analyze the accident record and determine which accidents might be preventable by PTC. In order to accomplish this task, the accident review team categorized four design concepts to reflect the broad range of capability that can address the PTC safety objectives, depending on operating territory and amount of risk reduction justified.

The levels identified were based on the differing functionalities of four PTC projects (i.e., the BNSF TrainGuard™ System Project, the Union Pacific Railroad (UP)/Burlington Northern Santa Fe (BNSF) Positive Train Separation (PTS) Pilot Project, and the Amtrak/Michigan DOT Michigan Line Incremental Train Control System (ITCS) Project), and the design specifications originally proposed for the UP/Illinois Department of Transportation (IDOT) St. Louis Line Project that were based on the Advanced Train Control Systems (ATCS) Specifications.

The four design concepts are hierarchical, in that each superior design incorporates all of the functions of the previous concept(s), and may either add functionality or scope (coverage) or both. The design concepts, from the least functionality/scope, to the most, are as follows.

1. PTC Level 1

This is the first level PTC design concept to address the "core functions" as identified by the PTC RSAC:

- Prevent train-to-train collisions (i.e., positive train separation).
- Enforce speed restrictions, including civil engineering and temporary restrictions imposed by slow orders.
- Protection from train movements for roadway workers and their equipment operating under specific authorities.

This level of PTC is based on providing specific location information on nearby trains and roadway crews to the lead locomotive of a train. On-board enforcement is based on either the failure of the engine crew to acknowledge a warning of a nearby train, or roadway worker crew, or exceeding permanent or temporary speed restrictions.

Most of these systems will use a radio frequency (RF) link to provide information to the lead locomotive of a train.

2. PTC Level 2

The next level PTC design will depend on the issuance of specific movement authorities and the reporting of train and roadway crew locations to the authority issuer. In addition to the functionalities of PTC level 1, level 2 will provide:

- A computer-aided dispatch (CAD) system designed to prevent the issuance of overlapping authorities, and provide for the issuance and enforcement of additional speed limits and restrictions.

- A digital communications link between the CAD system and the locomotives.

3. PTC Level 3

This design concept in addition to providing the functionalities of PTC levels 1 and 2, will provide:

- Devices (Wayside Interface Units (WIUs)) that monitor each mainline wayside switch, signal, and protective device currently installed in traffic controlled territory, to reduce risk of operating over unsafe track. If new switches are required during implementation of a level 3 system, these switches will be tied into a wayside local area network (WLAN).

- WIUs in non-signaled territory that monitor switch and protective devices.

4. PTC Level 4

This is the highest level PTC design concept, and is largely based on the level 40 Advanced Train Control Systems (ATCS) specifications. In addition to providing the functionalities of PTC levels 1, 2 and 3, level 4 will provide:

- WIUs that monitor each mainline signal, switch and protective device. This may require the installation of devices on currently installed switches and protective devices.

- Additional protective devices, e.g., slide fences, anemometers, high water, dragging equipment, hot box detectors, etc.

- Additional track circuits, track continuity circuits or other risk reduction approaches for broken rail detection.

- Track forces terminals (e.g. laptops or other technology with data link) for roadway machinery to reduce the risk of accidents involving track forces outside their authority limits.

C. Introduction of PTC with other Methods of Operations

The railroad industry, with advocacy from the Federal sector, has pursued the development and implementation of communications-based train control systems for more than 15 years. The initial objective was to develop a train control system at less cost than conventional train control systems that provided equivalent or greater safety of train operations and business benefits. At least 12 projects have been undertaken during this time to develop communications-based train control systems, now colloquially termed Positive Train Control (PTC) systems.

Three technically successful projects were terminated or suspended, because of prohibitive costs, before progressing to full revenue implementation, for a variety of business and technical reasons. Several of the 12 projects are presently in various stages of development.

The developing PTC systems are works in progress evolving as technology changes. They appear to fall into three categories: Those that will become stand-alone systems; those that will be enhanced overlay systems; and those that will be pure overlay systems.

- A PTC system of the stand-alone type will not merely augment the existing signal control system but will absorb its functionality to the extent wayside signals may safely be removed. Safety computers at a central office, on the wayside, and on-board each locomotive will enforce the proper spacing of trains, all speeds and stop where a stop is required. Stand-alone PTC systems will become the method of train operations.

- PTC systems of the enhanced overlay type will be so interconnected with the existing train control system that its functionalities will be extended to equipment on-board each locomotive that will enforce all speed and stop requirements prescribed by both the PTC and signal systems. The existing method of operations may or may not change.

- PTC systems of the pure overlay type will provide for, among other things, enforcement of all speed and stop requirements while utilizing the existing method of train operations.

D. Technology Developments Addressing PTC Core Functions

1. Background

In late 1983, the Canadian National, British Columbia, Canadian Pacific, Burlington Northern, Norfolk Southern, Seaboard System, Union Pacific and Southern Pacific railroads jointly agreed to support an endeavor to identify operating requirements for a communications-based train control system. In 1984, under the auspices of the Association of American Railroads (AAR) and the Railway Association of Canada (RAC), the Advanced Train Control System (ATCS) project office was established. A technical consulting firm, ARINC, was retained to perform a technology assessment and design the system architecture with oversight provided by railroad officials.

The development of the initial specifications for ATCS, and subsequent revisions, took more than eight years to complete in an open forum process with railroads, vendors and the FRA participating in component drafting committees. The specifications are detailed enough to ensure component interoperability and system safety without limiting vendor ingenuity. The ATCS Specifications are currently managed by the AAR.

2. Prior Developments

a. Overview of the Advanced Train Control System (ATCS)

ATCS anticipated using off-the-shelf equipment and computers and comprised five major systems: the Central Dispatch System, On-Board Locomotive System, On-Board Work Vehicle System, Field System, and Data Communications System. Each of the systems fully complied with the ATCS specifications in an open architecture.

The Central Dispatch System consisted of two subsystems – a console from which the dispatcher managed train operations that was linked to the ATCS system, and the Central Dispatch Computer. The console provided both an information display and data entry capabilities for the dispatcher. The Central Dispatch Computer was actually two interlinked computers, one that processed information to and from the dispatcher and other ATCS components, and the other that managed train movements with the objective of guaranteeing safe operations and minimizing train delays.

The Locomotive System also consisted of two subsystems - the locomotive display and the on-board computer (OBC). The display provided the interface between the locomotive engineer and the OBC; it displayed information about location, route, speed, speed restrictions, maintenance-of-way work locations, messages concerning the train movement, controlled point status and dispatcher advisories. The display contained a terminal from which the locomotive engineer could send and confirm information digitally with the dispatcher, field offices and other vehicles. The OBC performed on-board data processing and safety checking and handled data transmitted to and from the dispatcher, other locomotives, roadway worker employees, and coordinated location tracking, enforcement, movement authorities switch monitoring and control, and health reporting. Transponders were placed along the railroad at strategic points (e.g., controlled points, approach to controlled points, interlockings, etc.) for location determination. An interrogator on-board the equipped trains read each transponder providing precise location, and track identification. At selected transponders, the OBC calibrated tachometers that were used to provide location in the intervening distances between transponders. The OBC was equipped with a track database which contained information on the transponder locations, distances between transponders, and track configuration.

The Work Vehicle System consisted of two subsystems - a display that provided the interface between a roadway worker foreman and ATCS, which permitted the foreman to communicate digitally with the dispatcher or other vehicles and to be aware of nearby track activity and a Track Forces Terminal that performed data processing and safety checking to manage the movement of equipped work vehicles through the ATCS system.

The Field System consisted of wayside interface units (WIU) that provided remote control and monitoring of field devices. The WIUs performed internal data processing and error-checking, commanded the movement of controllable devices (e.g., moveable bridges or power-operated switches), monitored non-controllable, and highway-rail grade crossing devices.

The Data Communications System was a digital data radio network operating in the UHF radio spectrum. The communications hardware consisted of front-end processors (FEP), cluster controllers (CC), base communications packages (BCP) and mobile communications packages (MCP). The FEP is the major entry point from the Central Dispatch Computer into the ATCS ground network and performs train location functions and protocol conversions. Each FEP is connected to several CCs. The CC is a routing node in the ground network, manages a base station and performs functions similar to the FEP but over a smaller geographical area (e.g., routing of messages to and from trains or wayside devices under its control). The BCP provides the interface to the ATCS radio frequency and may contain one or more base station radios (each on different channel pairs). Base stations may be connected to the Central Dispatch Office by land lines, leased lines, microwave, fiber optics or radio. The MCP is configured to perform an interface between the RF network and the locomotive computer and display; an interface between a RF network and a WIU; and/or an interface between the ground network and a wayside equipment controller (e.g., code line messages). A MCP is required at each wayside equipment location and on each lead locomotive and selected roadway worker vehicles to transmit and receive messages. The ATCS data transmitted over the network included message protocols that required a handshake (closed loop) in order to become effective or be implemented.

b. Overview of Canadian National ATCS Projects

The Canadian National (CN) had three ATCS test or pilot projects between 1987 and 1995. The first, undertaken jointly with the AAR between 1987 and 1989, was the development of a pilot locomotive display. The project used Canadian National's locomotive trainers and a human factors expert and the display was tested extensively on CN's locomotive training simulator.

Between 1989 and 1992, the CN developed an ATCS test bed near Toronto, Ontario to demonstrate the concepts of ATCS. This test bed, designed to operate transparently to the revenue operation, consisted of an office system linked to the dispatch system, locomotive systems and Wayside Interface Unit emulators. The system demonstrated the feasibility of train tracking, and the verification and issuance of movement authorities from the office system. The time to deliver and display authorities was less than 3 seconds. In addition, the tests demonstrated the feasibility of co-existence of train control messages and administrative messages.

Between 1989 and 1995, the CN developed a transponder-based system using the AAR ATCS specifications as a foundation for system architecture, functionality, and communications. The system was designed for use in dark territory as a lower-cost alternative than CTC, and used CN's Computer-Aided Manual Block System (CAMBS) as a front-end dispatch system. It was connected to an ATCS Interface Computer (IC) which converted Occupancy Control System (OCS) clearances into ATCS Movement Authorities. The authorities were displayed on the ATCS IC graphical monitor for verification prior to being transmitted to the locomotive.

The territory was 188 miles long and had 13 sidings equipped with power switches monitored and controlled by Wayside Interface Units. The primary method of switch control was through the locomotive, either automatically when the train was operating with a Proceed Authority, and through locomotive engineer action when operating with a Work Authority. Switch position was displayed in the locomotive cab. Switches could also be controlled from the dispatch office for unequipped locomotives and engineering work equipment. The time from initiating the command to controlling a switch to confirmation on the locomotive display was approximately 15 seconds.

The system supported enforcement of permanent, temporary, and turnout speed restrictions. It also supported the protection of track force work limits, into which a train could enter only after a password provided by the track foreman by voice radio, was entered into the on-board system by the train crew and verified by the on-board system. The system included reactive enforcement of authority limits, and a form of predictive enforcement to prevent trains from traversing a switch that was improperly set.

In addition to the pilot territory, the CN equipped 40 miles in southern Ontario as a test bed. The project was a technical success, but was terminated when the industry appeared to be moving away from the ATCS program, as the CN did not wish to be the only one adopting the ATCS technology.

The system was developed by Alcatel Canada; the system supplier and integrator were Vapor Canada and Motorola Canada, respectively.

c. Canadian Pacific Railway ATCS Pilot – Calgary to Edmonton

The Canadian Pacific Railway (CP) operated a revenue-service ATCS pilot on 190 miles of mainline track between Calgary and Edmonton between 1993 and 1995. The objective of the revenue-service pilot was to develop an ATCS system in incremental steps with the constraints that each step must include: 1) a fall-back path to the previous step, 2) a progression path to the next step, and 3) thorough testing before revenue service implementation.

Technology pilots at the CP in the 1980s and 900 MHz radio testing in the late 1980s and early 1990s preceded the operational pilot and proved the technical viability of the major subsystems. Fourteen locomotives were then equipped for ATCS operation, with an additional four being partially equipped as spare locomotives should any of the 14 be removed from service. In-track transponders were then installed between Calgary and Edmonton and 900 MHz ATCS radios were added to existing radio towers to provide continuous radio coverage. During this time, the office dispatching software was upgraded to include a digital communication path to and from locomotives. This path provided for the transmission and acknowledgment of clearances to, and the reception of track releases from, locomotives. This was in addition to the existing human interface used for voice dispatching.

The pilot project proved the operational advantages of the electronic delivery of clearances and track releases but also the high cost of maintaining the prototype equipment used. The costs of maintaining such a system were found to be prohibitive, both for retrofitting existing locomotives and for using a transponder-based location tracking system. Reactive and predictive on-board enforcement of authority limits were shown to be effective, although predictive enforcement required more extensive testing before it could be considered for revenue service use. The pilot was shut down in 1995 due to the rising costs of maintaining a prototype system in revenue service. The pilot successfully demonstrated that an incremental approach allows for a manageable migration from existing operations.

As a postscript, the ATCS frequencies have proven to be a good choice for codeline replacement. The CP is completing a 900 MHz trackside radio network for radio codeline and envisions using any spare capacity to support other trackside data applications. This network will support ATCS communications in major corridors when the time comes.

d. Overview of the Advanced Railroad Electronics System (ARES)

ARES was conceived in 1983 by the Burlington Northern Railroad and the Collins Air Transport Division of Rockwell International. Following tests of data radios and GPS on two locomotives in the Minneapolis-St. Paul area in 1984, the BN contracted with Rockwell in1985 to develop and test ARES in revenue service operations. ARES had an architecture similar to that of ATCS and consisted of three major segments, the Control Segment, the Data Segment and the Vehicle Segment. It was built to proprietary specifications developed by BN and Rockwell; components were supplied by Rockwell, by railroad equipment suppliers such as Harmon, Pulse, and Union Switch and Signal, and by avionics suppliers such as Trimble Navigation and King Air.

The Control Segment consisted of computers and consoles from which dispatchers could monitor the position, velocity, and health of all trains and roadway worker vehicles and issue movement authorities. It also included a tactical traffic planner and strategic traffic planner, and accessed information about train consists, crews, and work orders from other railroad data bases. The Control Segment monitored activity to ensure that vehicles followed proper operating procedures and warned the dispatcher of impending violations of limits of speed and authority. It also performed conflict checking of movement authorities before they were transmitted to trains and roadway worker vehicles. For the test program, Control Segment equipment was installed at BN’s dispatching office in Minneapolis, Minnesota, and locomotive health monitoring stations were installed at BN’s locomotive shop at Superior, Wisconsin, and at BN’s operating headquarters in Overland Park, Kansas.

The Data Segment consisted of a digital data link communications network that provided data paths between the Vehicle Segment and the Control Segment. It consisted of equipment similar to that of ATCS: FEPs, CCs, BCPs, MCPs, and WIUs. Digital data messages were routed by the FEPs and CCs to BCPs at base stations. The base station BCPs provided an interface to mobile vehicles for movement authorities, restrictions, and work orders and to wayside equipment to monitor and communicate the status of hand-operated switches, power-operated switches, and signals through the network to the dispatcher. The ARES message protocols required an “electronic handshake” for the discretely addressed messages to become effective or be implemented. For the test program, BN installed the Data Segment along the 230 miles of track connecting the Mesabi Iron Range in northern Minnesota with the port of Superior, Wisconsin. Portions of the route were traffic control territory, automatic block signal territory, and non-signaled territory. BN used VHF radios (160 MHz) to transmit and receive messages between vehicles and the BCPs, and between WIUs and BCPs. BN's existing backbone communications network, consisting of microwave and of leased circuits, was used to convey the messages between the BCPs and the Control Segment.

The Vehicle Segment included computers and other equipment on locomotives and maintenance-of-way vehicles. "Lead" and switcher locomotives were equipped with odometers and GPS receivers to calculate train position and speed, all road locomotives were equipped with health monitoring systems, and all locomotives were equipped with data radios to communicate with the Control Segment. Two displays on each "lead" locomotive informed crew members (using both text and graphics) about movement authorities, the route ahead, work along the route, and the health of locomotives in the consist. Each "lead" and switcher locomotive was equipped with an on-board computer containing a track data base and with a throttle-brake interface to apply a full-service brake application if the on-board computer determined the train was about to violate its movement authority or speed limit. Each roadway worker vehicle was equipped with a GPS receiver to calculate location and speed, a data radio to communicate with the Control Segment, an on-board computer, and a printer to receive warrants, bulletins, and work time in the field. Locomotives and roadway worker vehicles periodically reported their position and speed to the Control Segment. For the test program, Vehicle Segment equipment was installed on all 17 locomotives (9 road locomotives - 6 designated as "lead" and 3 as "trailing" - and 8 switchers) and 3 maintenance-of-way vehicles that operated on the Iron Range.

The test bed was operated continuously from late 1987 through 1992 to successfully develop, test, and prove ARES technology.

e. Overview of the Positive Train Separation (PTS)

In 1994, the Union Pacific and Burlington Northern (now Burlington Northern Santa Fe) jointly embarked upon development of a Positive Train Separation (PTS) system. GE Harris Railway Electronics was retained to develop and test PTS. PTS had three major segments: the Locomotive Segment, the Communications Segment, and the Server Segment. PTS utilized the communications network that exists on each railroad with only minimal changes. BNSF used a VHF network and UP used a UHF network. The Locomotive Segment and Server Segment were built to UP/BNSF and GE Harris specifications in an open architecture.

The Locomotive Segment consisted of an on-board computer (OBC) with a cab display. Each locomotive was equipped with a GPS/DGPS receiver, and a mobile communications package (MCP), connected to the OBC. The OBC contained a track database and performed data processing to monitor location, calculate braking curves, calculate speed, receive authority limits, and apply the brakes if the authority or speed limits were projected to be exceeded. The OBC transmitted position data and violation messages to the server. Buttons on the bezel of the display provided means by which the locomotive engineer could digitally communicate with the dispatcher.

The Server computer Segment was interfaced to a console from which a dispatcher could monitor and direct train movements and to the communications segment for transmitting and receiving data to and from trains. The Server generated movement authorities on the basis of those issued by the dispatcher, established and transmitted authority and speed limits to trains, and received position data and violation messages from trains.

The communications segment on the UP provides data paths in the UHF radio spectrum between the mobile equipment, wayside equipment and the control center. The communications segment on the BNSF provides data paths in the VHF radio spectrum between the mobile equipment, wayside equipment and the control center. Both communications networks consist of equipment similar to that described for ATCS: FEPs, CCs, BCPs, and MCPs. The message protocols of both systems contained the requirement for acknowledgment (closed loop) in order to become effective or be implemented.

In 1996, PTS was installed in a test bed extending from Blaine, Washington to Pasco, Washington, on the BNSF, and between Vancouver, Washington and Hinkle, Oregon, on the UP, a total of about 865 track miles. The segment between Tacoma, Washington, and Vancouver, Washington, is joint trackage on which base stations operating in the UHF radio spectrum was installed in order to achieve PTS interoperability between trains of the two railroads. PTS prototype equipment (wiring harnesses, brake size modifications, sensors, housing and brackets) was installed on 16 locomotives, 10 on the BNSF and 6 on the UP. The test bed was utilized to successfully develop, test, and prove PTS technology. The PTS project was completed in August 1998.

PTS is an enhanced overlay system that essentially controls the movement of trains. PTS is designed for installation in any method of operation. This centrally controlled system will provide for safe and efficient train operations, protection of roadway workers, speed enforcement and stop where stop is required.

3. Current Developments

a. Overview of the Incremental Train Control System (ITCS)

In 1995, the Michigan Department of Transportation, in cooperation with Amtrak and Harmon Industries, was granted funding by the FRA for a demonstration of a high-speed positive train control system on an Amtrak line extending between Porter, Indiana, and Kalamazoo, Michigan. The system, identified as ITCS, consists of three major segments - the Wayside Equipment Segment, the Communications Segment, and the Locomotive Segment. Each of the segments was built to proprietary specifications developed by Amtrak and Harmon Industries.

The Wayside Equipment Segment is comprised of wayside interface units (WIU) at each controlled point, intermediate signal, electrically-locked hand-operated switch and highway rail grade crossing signal. The WIUs monitor switch position, track circuit occupancy and signal aspects displayed in the traffic control system and the status of highway rail grade crossings.

The Communications Segment consists of two parts – a spread spectrum wide local area network (WLAN) that connects the WIUs to wayside interface unit-servers (WIU-S) that in turn broadcast digital data messages to trains in the UHF radio spectrum. There are 8 WIU-Ss spaced up to 10 miles apart along the railroad. WIUs are slaves to WIU-Ss and continuously report via the

WLAN the status of the device(s) being monitored to their assigned WIU-S. The WIU-S broadcasts (open loop) the status reported by the WIUs once every six seconds. Each WIU-S is provided with a track database for the territory it serves including maximum authorized speed and speed restrictions. An office to wayside land line provides means for the control operator to issue or void temporary speed restrictions to the track databases of the WIU-Ss.

The Locomotive Segment consists of an on-board computer (OBC) and cab display. The cab display provides the interface between ITCS and the locomotive engineer by continuously displaying the maximum authorized speed, actual speed, distance to targets, type of targets, and target speeds. The OBC stores a database of signal indications, track curvature, gradients, mileposts, civil speed limits, speed restrictions, and the locations of all devices with which it may be required to communicate. The OBC continuously calculates braking distances to targets, monitors current speed and upcoming speeds, and initiates a full -service brake application if the maximum authorized speed is violated, or, the train is not properly slowed for an upcoming speed restriction or requirement to stop. The OBC establishes a session with each WIU-S when it enters its zone of coverage, verifies that it has an updated track database and expects to receive a WIU-S broadcast every six seconds. The OBC can miss two broadcasts without adverse affects but a missed third broadcast (18 to 20 seconds elapsed time) results in the OBC initiating an automatic brake application, stopping the train.

ITCS is designed to prestart highway-rail grade crossing signals at any train speed, and in this application at train speeds above 80 mph. The grade crossing signals have conventional approach track circuits designed to provide 30 seconds warning for train speeds of 80 mph. The approach to an active grade crossing system is determined by the OBC from the track database. At speeds above 80 mph, a session is then established via the WIU-S with the crossing WIU and the OBC provides an estimated time of arrival. If the crossing WIU indicates it is armed and functioning as intended, the train may proceed at speed and the crossing will provide the required 30 seconds warning. The estimated time of arrival at the crossing is updated every 5 seconds until the train reaches a point 30 seconds from the crossing. If a crossing does not arm or indicates it is not functioning as intended, the OBC will initiate a full-service brake application to slow the train before it reaches the crossing. ITCS will restrict the movement of subsequent trains at a failed crossing to 15 mph until the crossing device is repaired.

ITCS is installed in a test bed on Amtrak's Michigan Line between milepost 150 and milepost 216. Since 1995, the test bed has been utilized to develop, test, and prove ITCS technology. Implementation of ITCS is scheduled to begin in late 1999.

ITCS is an enhanced overlay system of modest cost when built on an existing traffic control system. ITCS will be deployed in high-speed territory, having light density traffic. The benefits of this distributed system include increased track capacity, higher speeds, protection of roadway workers, speed enforcement and stop where stop is required – characteristics which maximize safe and efficient train operations befitting installation in any traffic control system.

b. Overview of the Advanced Civil Speed Enforcement System (ACSES)

Amtrak has received FRA approval to install ACSES in the Northeast Corridor (Final order of particular applicability, FR39343, July 22, 1998). The project will expand the existing 4-aspect cab signal system to 9 aspects that will be augmented by ACSES. ACSES will utilize transponders of a European design in the expanded signal system to achieve maximum authorized speeds up to 150 mph, enforcement of civil speeds, temporary speed restrictions and absolute stop. Amtrak has retained a contractor to develop, test and implement ACSES, using off-the-shelf equipment in an open architecture.

The existing cab signal and train control system utilizes a 100 Hz coded carrier transmitted in the rails to provide for speeds of 20 mph (Restricted Speed), 30 mph, 45 mph and maximum authorized speeds up to 125 mph at code rates of 0, 75, 120 and 180 pulses per minute, respectively. The 9-aspect system will be achieved by the addition of a new 250 Hz coded carrier that, in combination with the 100 Hz coded carrier will provide aspects for enforceable speeds of 80 mph, 125 mph and 150 mph. The addition of a new code rate, 270 pulses per minute, will provide aspects for enforceable speeds of 60 mph and 100 mph.

Transponders will be placed in the approach to speed-restricted zones. The transponders will provide data to on-board equipment that includes distance to the beginning of a speed restriction, type of speed restriction, target speed, average grade to the restriction, distance to the next transponder, and message verification information. The on-board computer, through data from a tachometer, will monitor the train's performance and, if necessary, initiate an automatic brake application to prevent entering the speed restriction at a speed above that prescribed.

Transponders will also be placed in the approach to interlockings to provide for enforcement of absolute stop when the interlocking signal displays an aspect requiring stop.

The initial installation of ACSES is underway between New Haven, Connecticut and Boston, Massachusetts.

ACSES is another integrated, or enhanced overlay system being built on existing wayside systems. The ACSES will be employed in high-speed territories having traffic of a high density. This distributed system will provide for increased track capacity, higher speeds, protection of roadway workers, speed enforcement and stop where stop is required, functionalities which maximize safe and efficient train operations, and could be installed in any multiple track territory having existing signal systems. The system is highly suitable to high-speed passenger train and commuter operations.

c. Overview of the New Jersey Transit Project (NJT)

A project similar to and compatible with Amtrak's ACSES system is the Advanced Speed Enforcement System (ASES), planned for installation on 310 route miles of the New Jersey Transit (NJT). NJT also connects with Amtrak in New Jersey and operates about 310 trains daily over that part of the Northeast Corridor extending between New York City and Philadelphia, Pennsylvania and over the Atlantic City Line extending between Philadelphia and Atlantic City, New Jersey.

Like ACSES, ASES will be transponder-based to provide for enforcement of civil speeds, temporary speed restrictions, and absolute stop where stop is required. Installation of a nine-aspect cab signal system on-board NJT locomotives will provide the interoperability necessary to operate at higher speeds and closer headways in the Northeast Corridor.

Like ACSES, ASES is an integrated, or enhanced overlay system being built on existing systems. The ASES system will be employed in commuter rail territories having high density traffic. This distributed system will provide for increased track capacity, higher speeds, protection of roadway workers, speed enforcement and stop where stop is required, and will be interoperable with ACSES. The system is highly suitable to high-speed passenger train and commuter operations.

It operates in conjunction with, and enhances the capabilities of existing and future ATC systems, and is functionally compatible with the Advanced Civil Speed Enforcement System (ACSES) and nine-aspect high-density ATC being installed on the NEC high-speed lines. This will preserve the interoperability necessary for the NJT fleet to operate fully on the NEC. ACSES fixed transponders are logically linked so that at any point, the system knows the expected location of at least the next transponder. Portable transponders will be used to enforce temporary slow orders and work zones. They will be located braking distance away from the restricted zone, much as the approach and approach speed limit signs are used today. Obtaining the physical as well as dynamic features of the railroad will allow the on-board computer to enforce a target speed limit or stopping point with a precision braking profile without the need to maintain an on-board database. The on-board ASES computer integrates PTS target speed and positive stop enforcement features with the ATC system and conveys the information continuously to the locomotive engineer on a readily interpreted graphical display.

In December 1997, US&S was awarded a contract to design and furnish the complete ASES, including a demonstration on five types of motive power and control cars. The ASES will be installed on 109 locomotives and cab cars and the intermittent PTS equipment will be added to 46 track miles where existing wayside signal systems will not be immediately equipped with ATC. Final prototype demonstration occurred in March and April 1999. Current projections have the functional system in service by December 1999.

Other railroads operating over NJT ASES equipped lines will be required to have their trains equipped with ASES, unless FRA waiver precludes this requirement.

d. Overview of the CR/CSXT/NS Positive Train Control Platform Project

In 1997 and 1998, Conrail, CSX Transportation and Norfolk Southern railroads received a grant from the FRA to develop, test, and demonstrate an on-board PTC platform.

A determination was made that the design specifications would be object-oriented with a standard locomotive bus. The objective is to develop an on-board platform which will accommodate inputs from any type of system governing the method of train operation (e.g., block signal systems, ATCS, ARES, PTS, ITCS, etc.) in order to facilitate interoperability.

The project was scheduled in two phases. In Phase I, the plans are to complete the design specifications to develop two prototypes, contract for prototype hardware and complete the testing of prototypes. In Phase II, the plans were to issue a request for proposals to develop functional specifications for off board objects and systems prior to implementing a PTC demonstration between Manassas, Virginia and Harrisburg, Pennsylvania. WABCO completed the design specifications in an open architecture with the standard messages. WABCO and GE-Harris were selected to build prototypes to prove the specification and Safetran was selected to provide two individual "objects" to be tested for interoperability with the WABCO and GE Harris systems. A contract for the development of functional specifications will be issued in 1999, and a demonstration will be conducted by 2001, contingent upon continued FRA funding.

If successful, the on-board platform can be utilized on locomotives that operate in multiple PTC systems and other methods of operation. One of the objectives of the platform design would be to enable cost reductions in equipment and promote interoperability among the various systems.

e. Overview of the TrainGuard™

TrainGuard™ was conceived in a Burlington Northern labor/management safety committee in early 1993 as a means to make train crew members aware of other trains in their vicinity in non-signaled territory. Following the merger of the Burlington Northern and Santa Fe railroads, further development of the proximity warning system was assigned to the BNSF's Technical Research and Development staff which has vigorously pursued TrainGuard™ development. The BNSF retained Pulse Electronics (now WABCO Railway Electronics) to design and develop a system.

TrainGuard™ only has equipment on-board the locomotive, and consists of an on-board computer (OBC), display, GPS receiver and mobile communications package (MCP) integrated with the front end unit of the end-of-train device (EOT) that transmits in the EOT UHF bandwidth (450 Mhz). The OBC is provided with a track database that includes track curvature, grade, interlockings, signals, crossings and civil speed restrictions. The OBC uses GPS data, tachometer data and gyro data for location determination. Every 15 seconds, the MCP broadcasts the locomotive identification number, location, speed, direction, and stopping distance. Data transmitted from the controlling locomotive of another train are displayed in graphics and text showing the train's identification, distance, speed, direction, stopping distance and age of the last radio communication received. The locomotive engineer is required to acknowledge alerts announcing the proximity of a new train, impending overspeed conditions and alerts indicating the threat of nearby trains. The OBC initiates an automatic brake application if an alert is not acknowledged, the train is overspeed or the stopping distance to another train is about to be violated.

Wayside communications networks are not required for TrainGuard™ except in areas where MCP transmissions do not have coverage of 5 to 7 miles. In that event, wayside repeaters are installed to provide that coverage. The messages broadcast by the MCPs on locomotives and repeaters are open loop.

No central office equipment is required to support TrainGuard™ though a means is being developed to digitally update on-board databases including temporary speed restrictions. In the interim, temporary speed restrictions will be manually inputted into the OBC by the locomotive engineer.

The BNSF is installing a TrainGuard™ test bed between Barstow and Los Angeles, California, including a roadway worker vehicle, to test TrainGuard™ in the railroad environment. TrainGuard™ is intended to be a low cost PTC system that fulfills the functionality requirements established and agreed to by the RSAC.

TrainGuard™ , is a pure overlay system under development solely for the prevention of collisions, speed enforcement and roadway worker protection. The TrainGuard™ system resides on-board locomotives, can be installed in any territory and is neither affected by nor affects the method of operation. TrainGuard™ limitations include the lack of information concerning signal indications, switch positions and movement authorities.

f. Overview of the Communications-Based Train Management System (CBTM)

CSX Transportation (CSXT) has embarked upon the development of a PTC system identified as CBTM. CSXT has retained WABCO Railway Electronics to develop and test CBTM using the object oriented design concept and the CR/CSXT/NS joint platform design. The CBTM design will be an open architecture.

CBTM will provide for the RASC core features in non-signaled territory: prevent collisions between trains (except where speed is 8 mph or less); prevent overspeed of trains; and protect roadway worker work zones from unauthorized intrusion by trains. CBTM will provide databases at wayside Zone Controllers that provides for enforcement of mandatory directives. CBTM will issue targets enforcing stop at the end of movement authorities; issue targets for speed reductions, monitor switch positions (CSXT has applied for a waiver of CFR Part 236.6); and protect roadway workers work zones. The on-board computer (OBC) will calculate braking distances, calculate the distance of the train to the far limits of authority, and initiate an automatic brake application at speeds above 8 mph when a violation is projected.

A testbed in non-signaled territory has been selected for testing CBTM concepts. The objective of CBTM is to design a system that meets the RSAC core objectives while providing an approach that permits the locomotive fleet to be economically equipped and interoperability achieved.

CBTM is an overlay system that enforces against improper movement of trains. CBTM is designed for deployment in non-signaled territory where the method of operation is by mandatory directives. The system is designed to enforce the limits of authorities and monitor the position of switches. This centrally controlled system will provide for protection of roadway workers, speed enforcement and stop where stop is required, except where the speed is 8 mph or less.

g. Overview of the Alaska Railroad Corporation Project (ARRC)

Early in 1998, the Alaska Railroad Corporation (ARRC) launched a program to install Precision Train Control^{TM} (PTC) systemwide. The AARC PTC is a development of GE Harris, the system engineer on the project.

The ARRC PTC is a derivative of the UP/BNSF PTS project. Like PTS, PTC has three major segments: the Locomotive Segment; the Communications Segment; and the Server Segment, which requires support of a computer-aided dispatching (CAD) system. Unlike PTS, PTC will include a Track Forces Terminal (TFT) for roadway employees. The TFT will provide location and tracking of roadway worker on track vehicles and digital communications for obtaining and releasing work zones for the protection of roadway employees.

The ARRC has completed installation of a communications system to support PTC. A CAD system has been delivered and is scheduled for implementation in the fourth quarter of 1999. Deployment of PTC is scheduled for the first quarter of 2000.

The ARRC system is an enhanced overlay system designed to control the movement of trains. The ARRC system is designed for non-signaled territory where the method of operation is by mandatory directives, and when deployed will be a stand-alone system. The system is designed to enforce all speeds and the limits of authority, but has no provisions for detecting broken rails or the position of switches. This centrally controlled system will provide for safe and efficient train operations through increased track capacity, protection of roadway workers, speed enforcement and stop where stop is required. The ARRC system will be installed in rugged Alaskan terrain and will enhance the safety of passenger and freight train operations across the railroad.

4. Emerging PTC Developments

a. Overview of the Norfolk Southern Location System (NSLS)

NSLS is a recently emerging system for which specifications have not yet been completed or published. It is a proximity warning system that is being designed in-house on the Norfolk Southern railroad. NSLS is similar to Train Guard in that its concept is to inform train crew members about other trains in the vicinity.

NSLS will utilize transponders located at each signal location that provide information to on-board computers about the location, distance to and location of the next two transponders, maximum authorized speeds and civil speed restrictions. The on-board computer (OBC) will consist of an interrogator for reading transponders, a display and a mobile communications package (MCP) for transmitting data from the OBC. NSLS utilizes a tachometer to determine position between transponders. When a train passes a transponder, the locomotive identification, location, speed and direction will be periodically broadcast in the Norfolk Southern's End of Train Device VHF radio spectrum. The VHF broadcast is expected to cover about seven miles. When another train enters or is within the coverage of a train, its identification, speed and direction will be displayed to the locomotive engineer and acknowledgment required. When two opposing trains identify the same second transponder in advance, a safe braking distance is determined causing the OBC to initiate automatic brake applications on both trains**.**

The Norfolk Southern is continuing to develop the design of NSLS, including possibly displaying signal aspects on the display. NSLS is intended to meet the PTC RSAC objectives**.**

The NSLS is a pure overlay system under development solely for the prevention of collisions, speed enforcement and roadway worker protection. The NSLS system resides on-board locomotives and receives track data from transponders embedded in the roadway. It can be installed in any territory and is neither affected by nor affects the method of operations. NSLS does not use information from the signal system, nor does it monitor switch positions and movement authorities. This system will elevate the level of safety in non-automatic train control or non-automatic train stop territories by enforcing most speeds and stopping distances to other trains and equipped roadway workers, but will not enforce all speeds or a stop where a stop is required.

b. Overview of the AAR/FRA/Illinois Department of Transportation (IDOT) Positive Train Control Project

The FRA instituted this program jointly with the AAR and IDOT to design, test, build and install a PTC system on a segment of the Union Pacific Railroad extending between Springfield, Illinois, and Mazonia, Illinois, about 120 miles. The railroad industry agreed to participate with the FRA and IDOT through the AAR and its subsidiary, the Transportation Technology Center, Inc. (TTCI).

The objectives of the project are to develop, test and implement a cost-effective and interoperable PTC systems, including flexible block operations, and advance activation of highway-rail grade crossing signals in a corridor with both freight and intercity passenger service. In addition, the system must meet the safety objectives of preventing train-to-train collisions, enforce speeds and speed restrictions, and provide protection for roadway workers and their equipment.

On July 15, 1998, TTCI issued a request for proposal seeking a system engineer for the PTC program. The submissions of the offerors were reviewed and a selection was made. The project is projected to require four years to develop, test and implement.

The IDOT project will be a stand-alone, centrally controlled system. It represents the most technically challenging of PTC systems as a result of assimilating the functions of the traffic control system and highway-rail grade crossings into the PTC functions. Inclusion of these safety and control functions, along with PTC functions that provide interoperability, precise train location, flexible block operations, roadway worker protection, speed enforcement and stop where a stop is required is intended to provide unequaled robustness for safe and efficient train operations. These characteristics are intended to make components of the IDOT system suitable for installation in any corridor and to provide increased capacity on lines with mixed traffic, including high-speed passenger trains.

c. Comparison of the PTC Projects

The ATCS specifications were developed by the railroad industry with participation by suppliers and the FRA. The intent was to provide for both interoperability across railroad control systems and interchangeability between supplier products for such systems. The ATCS supported a range of communications-based applications including, health monitoring, codeline replacement, work order reporting and positive train control to be hosted on the communications network. The specifications included standardized communications methods, train control messages, and the response to those messages.

The ATCS specifications provided for a modular approach to train control implementation. The railroads could build train control systems to meet the requirements for various operating conditions ranging from light density to heavy density lines. While ATCS specifications provided a basis for new system development, current technologies often exceed the scope of that original work.

A Matrix of PTC Systems (see Appendix B) identifies the characteristics of the systems in 10 PTC projects. The matrix is composed of 14 categories containing data relative to each PTC system. Four categories, Architecture, Office Segment, Communications Segment and Locomotive Segment, identify the functionalities that set the systems apart from one another in terms of capabilities and deficiencies with regard to the safety of train operations.

The PTS, IDOT, CBTM, and ARRC systems will be centrally controlled from CAD systems, while the ITCS, ACSES, Train Guard, NSLS, and NJT systems will be distributed systems even though installed in centrally controlled systems.

Two systems, IDOT and ARRC, have the objective to be stand-alone systems. Three systems, ITCS, ACSES, and NJT are integrated systems. Four systems, PTS, Train Guard, NSLS, and CBTM are overlay systems. The CR/NS/CSXT project is a developing platform technology that will be utilized in the IDOT and CBTM projects.

The ITCS, ACSES and NJT systems are most potent from the perspective of safety of train operations. These systems derive functionalities to enforce all train speeds and stop where a stop is required from wayside signal systems that are designed and arranged to provide proper switch position, track and route integrity and spacing of trains. Protection of roadway workers is achieved by inputting work zone locations in databases on-board the locomotive via transponders or data radio. The strength of these systems is integration with the wayside signal system where safety resides except for speed enforcement. The wayside signal indications provide a redundant overview to the locomotive engineer about the authority displayed in the locomotive cab. Further, the wayside signal systems provide immediate fall back to operations by signal indications in the event of failure of on-board equipment. ACSES and NJT utilize proven technologies available off-the-shelf and, unlike ITCS, are not dependent upon an extensive communications network between trains and the control center or wayside. A weakness in the ACSES and NJT systems is ensuring transponder data is correct, especially in portable transponders used for the protection of roadway workers.

The PTS, CBTM, and ARRC systems enforce all train speeds and stop where stop is required from movement authorities issued to each train by CAD systems. These PTC systems require a communications network with high reliability and availability for transmitting and receiving data between trains and safety computers located in the central office, or on the wayside. The strength of these systems lay in databases either on-board or on the wayside that, in connection with GPS technology, provide precise train location for enforcement of all speeds and stop where a stop is required. Protection of roadway workers is accomplished by inputting the work zones and their associated speeds into the databases. CSXT operating rules require crew members to have a hard copy of applicable train messages and receive their block authorities verbally from the dispatcher. CBTM makes this authority information available to the crew only after enforcement. The CBTM system does not enforce speeds or stop commands at speeds below 8 mph, however, warning messages are still displayed. Failure of the on-board equipment in the ARRC system, and PTS in automatic block signal or non-signaled territory, will require fall back operations to copying and repeating mandatory directives for movement of the train.

Trainguard and NSLS are systems that prevent train-to-train collisions and provide roadway worker protection with data transmitted by other trains or roadway equipment in close proximity. While they are locomotive on-board systems that supplement existing methods of operation or wayside signal systems, they do not enforce limits of authority or restrictive signal indications in every case. A limitation of both systems is a dependence on antenna and equipment on locomotives that may unknowingly degrade transmission and reception of train location data due to being an open loop.

The IDOT system will enforce all train speeds and stop where stop is required from movement authorities issued by the CAD system and central safety computer of which the wayside traffic control signal system will become an integral part. The system will require a communications network with high reliability and availability for transmitting and receiving data between trains and safety computers located in the central office or on the wayside. The strength of this system is complete integration with the wayside signal system where safety resides to provide proper switch position, track and route integrity, and in databases either on-board and/or on the wayside that, in connection with GPS technology, provide precise train location for enforcement of all speeds and stop where a stop is required. Protection of roadway workers will be accomplished by inputting the location of work zones and their associated speeds into the databases. Interoperability with other PTC systems will increase the vigor of the IDOT system. The development of flexible block operations, desirable for increased track capacity, will result in the removal of wayside signals. Elimination of the wayside signals is an economic benefit but exposes a weakness by excluding redundant support of information displayed on-board the locomotive. Special requirements will be necessary to mitigate hazards associated with train movements experiencing failure of on-board PTC equipment since there will be no wayside signals in essentially a traffic control system.

E. Role of PTC in Utilizing Information from Wayside Detectors

Wayside detectors monitor passing trains for defects, and conditions on the track or roadway that may affect the safe operation of approaching trains. Monitored defects may require immediate action or may require future maintenance. Wayside detectors may provide information directly to the train, to wayside signal systems or to remote systems (e.g., dispatch or other systems).

Examples of existing devices that monitor passing trains include:

- Hot bearing detectors
- Hot wheel detectors
- Flat wheel detectors
- Dragging equipment detectors
- High-Wide load detectors
- Truck performance monitors
- Acoustic bearing detectors
- Automatic Equipment Identification readers

Examples of devices that monitor wayside devices, track conditions or weather include:

- Switch position detector
- Track circuit/signal aspect monitor
- Slide detector
- Grade crossing warning system condition monitor
- High water detector
- Bridge integrity detectors
- High wind detectors

The objective of detectors is to report unsafe conditions and maintenance requirements. Coordination of these devices with a PTC system would appear to be an appropriate application of the technology, although not a core feature of PTC.

In present day operations, the communication link between detector and train is handled in many different ways, depending on the detector type, the host railroad and site-specific conditions. For example, hot bearing detectors are often equipped with "talkers" that transmit a voice message over the train radio channel to the crew, describing either an "all clear" status or the specific nature and location of the defect. Other types of train defect detectors may use a similar method, or may simply trip an alarm that sets the signal system to stop the train. In other cases the detector may transmit the information to a central monitoring point for support of maintenance decisions.

With PTC systems, the data link to the train may be used to deliver the information directly on-board for display to the train crew and/or automatic response by the train's on-board computer system. However, given the variety of different architectures of PTC systems currently under evaluation, the means to link the detectors themselves with the wayside-to-train communication link will vary with the PTC architecture in use. In some situations, it may be appropriate to provide a direct link between the detector site and the train. In other cases this may be inconsistent with the protocol of the wayside-to-train data link, requiring instead a "land-line" connection between the detector site and the source of wayside-to-train messages, whether that source be a central dispatch facility or a distributed zone controller of some type that handles a somewhat more local area.

If the detector's link is to another ground-based facility, then the physical means to transfer the information may be optimized for any given situation, so long as the integration of the detector data into the train's authority message stream is consistent with interoperability requirements. There is still some value in having standards for the ground-to-ground communication link in terms of compatibility of different vendor products, but these benefits are unrelated to the application of PTC. If the link is directly between detector and train, then the detector site itself must be carefully designed and equipped to meet any pertinent interoperability standards. If PTC is coordinated with wayside detectors, maintenance, inspection, and testing procedures need to be explored.

Provided the data links have the needed capacity and do not introduce too much latency in the message delivery, the use of a PTC link for any of these detector applications has the potential to improve the timeliness of getting urgent safety information where it is needed. For example, in a wayside monitoring application, a rock slide detector could deliver its warning directly to the train, wherever the train is. In the typical current process of tripping a wayside signal when the detector is activated, if the front of the train has already passed the signal, there is no way to get the warning to the train. Conversely, if the train can respond, it will generally have to run at restricted speed for several miles with no clue as to whether the problem is an occupied track, broken rail, open switch, or rock slide. Also, identifying the cause of the alarm as a slide detection would give the crew a much better clue as to what to look for and pinpoint the location to the exact area of the slide detection device.

Latency and capacity concerns involved in message delivery time are an important design concern. Depending on many factors, the total time required to move a message from a wayside detector to the train needs to be as short as possible. Factors impacting this message latency time and capacity include the following:

- Complexity of the path the message must follow from source to destination.
- Competition with other messages that may be sharing various links in that path.
- Competition for processor time at any node where the message must be handled.
- Message prioritization in the overall communications architecture.
- Capability of the ground-to-train link protocol to deal with unplanned messages under various loading conditions.

The system architecture must be carefully designed to assure worst-case scenarios will not raise the latency to the point where performance becomes poorer than the independent methods in use today.

As electronically controlled pneumatic (ECP) braking becomes established in the industry, the need for wayside detectors to monitor for defects on trains may gradually be phased out. ECP braking brings with it an intra-train communication link that could support on-board defect detection on each car. At some point in the future, it may be feasible to expect all rolling stock to be equipped with devices to detect bearing problems, stuck brakes (a cause of hot wheels), flat wheels, and other mechanical defects. However, this is far enough into the future that there will be value for a long time in enhancing the wayside-based defect detection systems with improved communications through an interface with PTC.

F. PTC, ITS, and Highway-Rail Grade Crossing Safety

1. Overview

Of the 6,262[25] United States railroad accidents in 1997, 3,865 occurred at highway-rail grade crossings. These are the largest category of potentially preventable accidents that exist within the railroad industry. The reduction of these accidents has received significant attention from the railroad industry, Federal, state, local agencies, and other private entities such as "Operation Lifesaver." These groups have worked cooperatively in many areas seeking to prevent highway-rail grade crossing accidents. Railroads and public agencies currently spend $300 million annually to install, improve, and maintain highway-rail grade crossing warning systems.

These investments have paid dividends. Although train traffic and highway vehicle traffic operating over highway-rail grade crossings has increased during the past few years, accidents at these crossings have decreased from 6,615 in 1988 to 3,865 in 1997.

The highway-rail grade crossing poses special challenges to the transportation community. It is an intersection of the railroad network with streets or highways, where the railroad has and must maintain the ultimate right-of-way (*United States Supreme Court, Continental Improvement Company vs. Stead*). This is a complex problem that involves a number of interrelated systems. The failure of highway vehicle operators to obey traffic laws at grade crossings continues to be the most significant contributor to accidents, injuries, and fatalities at grade crossings. While stringent enforcement of traffic laws and regulations will contribute to compliance with those laws, further reduction of these accidents can also be achieved through elimination of crossings or the installation of active warning systems. Most highway-rail grade crossings are equipped with either active devices (i.e., flashing lights and/or gates) or passive devices (crossing signs). Active devices are installed where the train and highway traffic justify the additional cost.

The Intelligent Transportation System (ITS) Program was established when Congress passed the Intermodal Surface Transportation Efficiency Act in 1991. The United States Department of Transportation was encouraged to implement a national system of travel-support technology (communications, computers, sensors, and displays), smoothly coordinated between transportation modes and jurisdictions to promote safe, expeditious, and economical movement of goods and people.

PTC technology provides the opportunity, in conjunction with ITS, to improve grade crossing safety. PTC-provided data to ITS can support real-time information of train position and the estimated time of arrival at highway-rail grade crossings, and interactive coordination between roadway traffic management centers and train control centers. For example, remote monitoring systems could warn train control centers and/or traffic management centers of highway vehicles fouling the crossing and/or failures of active warning system equipment. PTC and ITS deployment may improve automated warnings at crossings and/or provide travelers with advanced

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[25] *Source:* Annual Report 1997 Railroad Safety Statistics, This number includes train accidents (includes highway-rail crossing) and highway-rail incidents.

warning of crossing closures. Just as highways and railroads intersect at grade crossings, the highway and rail information systems being contemplated can be made to interact as well. Although not a core feature of PTC, the coordination of ITS with PTC systems at the grade crossing is an opportunity that should be anticipated and planned for.

One critical issue involving coordination of PTC with highway-rail grade crossing warning systems and ITS is the potential liability associated with any non-traditional approach to the provision of safety-critical systems for public safety benefit. This is a particular concern when various parts of the system may be developed, supplied, owned and maintained by different parties (i.e., railroad, highway authority, and vehicle owner/operator). As PTC is coordinated with highway-rail grade crossing warning systems, procedures for the necessary testing, inspection and maintenance will need to be explored.

2. PTC/ITS Applications

Several PTC and ITS pilot projects have been or are currently being undertaken in the United States, involving new technological applications which have the potential to further improve highway-rail grade crossing safety.

C Michigan/Amtrak Incremental Train Control System (ITCS) Project

This project was undertaken in response to a FRA grant to test communications-based train control technologies for the operation of high speed passenger trains over areas not equipped with locomotive cab signals or train control systems. The ITCS has the ability to communicate with each grade crossing via data radio well in advance of actual arrival at the crossings. The communication requires the computer equipment on-board the locomotive to determine the "health" of the grade crossing while the train is still several miles away. ITCS verifies the following information:

- C Can the crossing warning system communicate with the train? If so, the train continues to proceed at maximum authorized speed. If not, the train must reduce to a predetermined speed prior to arrival at the crossing.

- C Through a self-diagnostic process, is the crossing warning system prepared to operate as intended? If so, the train continues to operate at maximum authorized speed. If not, the train must reduce to a predetermined speed.

- C Has the crossing warning system been operational for five minutes or greater with no train present (false activation)? If so, the train will be restricted to a speed of 15 mph over the grade crossing because of the probability of highway users ignoring the activation of the warning system.

No information is displayed inside the motor vehicle.

C Illinois Project

This project is still in the development stage and with respect to highway-rail grade crossings, has similar objectives as the Michigan ITCS project. This program will develop, test, and demonstrate PTC capabilities, including advance activation of highway-rail grade crossing warning systems, in a corridor with both freight and passenger service.

- **New York State/Long Island Railroad "ATLAS" Project**

The objective of this project, once implemented, is to provide a prediction of train arrivals to highway vehicles at crossings for traffic routing purposes. Crossing warning systems would be activated by radio transmissions from the approaching railroad locomotive. A display unit, mounted inside the cab of the locomotive, indicates if there is a stalled vehicle on the crossing. The railroad's train control system will have the ability to stop the train before arrival at the crossing if there is adequate braking distance for the train.

- **Los Angeles Metro Blue Line Project**

This light rail transit project demonstrates the ability to detect highway vehicles on a grade crossing when the crossing warning system is activated by the approach of a train to prevent the lowering of four-quadrant exit gates until all vehicles have cleared the crossing. Vehicles are detected by inductive loops which are buried in the pavement under the grade crossing. The loops have worked well at detecting moving vehicles, but tests revealed one blind spot in which a small stationary vehicle could go undetected.

- **Minnesota Guidestar Project**

One project activity of this program is to provide in-vehicle warning to a highway user of an approaching train. The warning system is activated from the train occupying a track circuit. A small transmitter located at the highway-rail grade crossing broadcasts a message of an approaching train to receivers in highway vehicles. A warning is displayed to the vehicle driver on a dashboard display unit.

The wayside transmitter continuously transmits a low power frequency that can only be received near the vicinity of the crossing. When this transmission is received by a highway vehicle, part of the dashboard display unit is illuminated to show that the vehicle is approaching the crossing. The wayside transmitter transmits two conditions: "warning system activated" or "warning system not activated." When activated, a small model of the cross bucks and flashing lights is displayed on the dashboard of the vehicle.

The system is currently installed on school buses and tests that include the sensitivity of the receiver are being performed.

Pilot Study of Advisory On-Board Vehicle Warning Systems

In May 1997, the Illinois Department of Transportation (IDOT) executed a consultant contract with Raytheon E-Systems to design, install, oversee, operate and maintain a demonstration system for a Pilot Study of Advisory On-Board Vehicle Warning Systems at Railroad Grade Crossings. IDOT is directing this pilot program that seeks to provide in-highway vehicle warning systems of an approaching train.

Approximately 300 vehicles will be outfitted with the on-board system from Cobra Electronics as part of this pilot study. The vehicle mix will include a variety of ground transportation vehicles in the study area including:

- School buses
- Emergency service vehicles
- Commercial vehicles that are primarily housed in the study area

The system will use low-powered communication transmitters located at the crossings that will be triggered by a train approaching or occupying the crossings. This transmitter will send a signal between 800 to 1,200 feet in all directions from the grade crossing and activate a receiver in any equipped vehicle within the range to alert the driver of a train's presence. The receiver in the vehicle will contain an audible, a visual, or a combination audible/visual warning. The pilot study area includes five grade crossings along the Metra-Milwaukee North Line equipped with detection and warning systems.

- **Mystic, Connecticut, School Street, Four-Quadrant Gate Installation**

This installation is located on Amtrak's highway-rail grade crossing in the Mystic section of Groton, Connecticut. The system consists of four gate arms that fully block the roadway, preventing motorists from going around the gates. A special crossing sensor system collects and transmits information about the operation of the grade crossing warning devices to the cab of an approaching train at a point where the train will have time to stop before reaching the crossing.

In the event a vehicle is disabled or stopped between the gates, the advance warning system will activate signals in the train cab and stop the train. Exit gates are left in a vertical position until the vehicle is off the crossing.

- **North Carolina Sealed Corridor Project**

This project's primary objectives are to determine highway-rail grade crossing warning system effectiveness, and using those outcomes to determine the systems needed to reduce risk. Highway median barriers, long gate arms, and four-quadrant gates were evaluated using video monitoring. In addition, video enforcement of grade crossing laws was instituted in Salisbury, North Carolina. The results of the evaluation showed that a significant reduction in the risk of grade crossing accidents can be achieved with the installation of long arm gates, median barriers, and four quadrant gates, and the enforcement of traffic laws using video cameras. Norfolk Southern and North Carolina DOT are currently implementing these systems from Greensboro to

Charlotte, North Carolina.

3. Future Technological Applications

The application of new technology at highway-rail grade crossings offers the future promise of:

- higher levels of highway user and train crew safety;

- greater warning system reliability and flexibility;

- improved functionality and interconnection with highway traffic control systems and devices; and

- increased deployment of active safety devices.

An important consideration in planning for the future functionality of highway-rail grade crossings involves compatible or even complementary developments in other sectors of the transportation system. One such complementary development pertains to ITS command and control systems which may improve the safety and efficiency of surface transportation systems. Using computer and communications technologies, many of the functions envisioned by advanced train control proponents are being adapted in ITS applications.

The design and implementation of an intelligent controller for ITS and PTC systems may serve as an effective vehicle to deliver accurate, timely, and critical information to highway users, as well as those responsible for managing urban traffic movements. Among the advancements envisioned with these dual developments in train control and ITS are:

- additional means to detect the presence of trains which may enhance the effectiveness of highway-rail grade crossing warning systems.

- improved emergency vehicle dispatching and enhanced urban mobility through the provision of real-time information on train activity.

- in-vehicle signing or warning systems for highway vehicles and/or on-track vehicles.

- improved interface with traffic management systems.

Potential applications include the following:

a. In-Vehicle Warning Systems

In-Vehicle Warning Systems are intended to alert or warn a driver of a highway vehicle about the impending approach or proximity of a train. FRA has participated with the Federal Highway

Administration and others in evaluating proximity warning systems for priority vehicles. Although exploration of technological options makes sense for the short term, it is not clear that the inherent limitations of most current approaches can be overcome. Those limitations include:

- **Cost**. Recovering the cost of train borne, wayside and/or vehicle hardware solely by preventing highway-rail crossing collisions seems unlikely. Although often deadly when they occur, these collisions are relatively infrequent considering the number of highway vehicles crossing annually at-grade. The number of highway vehicles, crossings, locomotives and on-track equipment that would have to be equipped is staggering.

- **False warnings**. Many concepts for in-vehicle warning would generate false warnings, because the system would not be able to discriminate real danger from mere proximity. In some systems, warnings would be provided to vehicles moving away from crossings and vehicles operating on parallel roadways. In areas of dense railroad operations, where risk is high, false warnings might be prevalent. False warnings will lead motorists to ignore or defeat the warning system.

- **"Uncovered" failures.** Many of the ideas for in-vehicle warning systems, particularly those that are less expensive, would not be fail-safe. Introducing technology that motorists may learn to rely upon, but that is not fail-safe, could actually degrade safety.

Integration of Positive Train Control systems with intelligent highway vehicles may ultimately permit presentation of a highly credible warning to a motorist approaching a crossing when a train is present or approaching. Such a system could reinforce the warning provided by automated warning devices at the crossing or, where the train horn is the only active warning system at the crossing, provide a more uniformly effective active warning at low marginal cost.

As an example, in order for one of the proposed systems to function properly and be affordable:

1) the transmission of adequate data would need to be a feature inherent in the PTC system;

2) the stream of information flowing to the highway side would need to be in a standard format;

3) the information would need to be transmitted to the vehicle on an ITS local frequency used for such purposes; and

4) in-vehicle intelligence provided for other purposes would need to be able to process the information.

This would require the highway vehicle to be equipped with a data radio receiver, a differential GPS receiver, a highway-rail database, a microprocessor, and appropriate software, together with the capability to provide an audible and visual warning. With the sole exception of appropriate application software, all of these elements will need to be installed on motor vehicles (particularly priority vehicles) in order to facilitate other ITS programs, such as warning of emergency vehicles approaching intersections.

The most immediately appealing approach to providing information from the rail side would be to broadcast train approach information in the affected area by simply declaring the identity of the train (by code) and time/position. If reliable, periodic transmission is practicable, the highway vehicle could then use the time and position information to determine the train's path and speed on the rail line. Alternately, the data package for each transmission could provide time, position, direction of travel and velocity. In either case, the transmission would need to be sufficiently frequent to avoid insufficient warning (should the train accelerate) or excessive warning (should the train slow) approaching the crossing.

The system could be made more nearly fail-safe if negative reports were required in each sector every five or ten seconds (depending on the size of the sector). Failure to receive such a broadcast when a highway vehicle is in the area of a rail line would trigger a prompt such as "TRAIN WARNING SYSTEM DOWN--USE CAUTION AT RAILROAD CROSSINGS."

Note that the stream of information flowing to the highway side would come from a data radio transmitter on the wayside. That installation would receive train position information from the central office or (acting as a zone server) from trains, handling the information required for a large number of crossings. This would be the most efficient approach, since a single train might be on a crossing and within 20-30 seconds of several other crossings at any given time. Broadcasting multiple messages containing the same information should be unnecessary. Managing this process to ensure timely reporting to the highway side is a major undertaking that must be considered as PTC systems are designed, verified, and validated.

However, where appropriate, controllers used to process PTS/PTC information for active warning systems at a crossing might also be employed to generate messages for in-vehicle warning as well. This information would need to be in the same format as information broadcast by sector.

b. Roadway Dynamic Displays

Dynamic displays include signboards and other visible information displays on the roadway that permit highway users to determine if it is prudent to traverse a grade crossing. These displays might be implemented at either active or passive crossings. The following modes of operation would be at the heart of the system:

- *No train approaching crossing;* **PROCEED:** Highway signal displays green "clear" indication, variable message sign is dark or displays "PROCEED" message.

- *Train approximately 60 seconds from entering crossing;* **CAUTION:** Highway signal displays yellow "caution" indication, variable message sign displays "TRAIN APPROACHING FROM RIGHT/LEFT" and "## SECONDS TO ARRIVAL" messages.

- *Train approximately 20 seconds from entering crossing;* **STOP:** Highway signal displays red "stop" indication, variable message sign displays "STOP" message. Remains in effect until the train has cleared the crossing.

While the above application has been recommended by the NTSB, there are many limitations which are inherent to the system and/or could provide a reduced level of safety from systems currently in use.

In the United States we recognize a pair of flashing red lights to mean that a train is approaching a highway-rail grade crossing. This system has been in use and accepted since the 1920s, and it is incorporated in Federal and state statutes. Providing a means of informing the highway user of the approach of a train, with devices other than flashing lights, may conflict with and detract from the instinctive reactions that the highway user has developed from life experiences. But equally important are the considerations that these alternate devices introduce. Dynamic message boards usually contain a written message. Should that message be only in English or multiple languages? How do we provide for the illiterate? Should we provide highway users with enough information to allow them to estimate if there is enough time to traverse the tracks before the train arrives; i.e., should we provide the time remaining before the train arrives? How should driver/pedestrian error be addressed? Currently railroad companies and employees are often held liable for driver/pedestrian non-compliance with existing warning systems. This is a concern that needs to be addressed in any new signage regulations.

In summary, flashing red lights are simple and well understood. Alternative warning devices may have a negative effect on safety.

c. Stalled Vehicle Detection

Early detection of stalled, disabled, or trapped vehicles blocking a crossing could permit a train to be stopped or slowed to restricted speed in anticipation of the blocked crossing.

Technologies currently being investigated for such an application include video imaging, radar, laser scanning and inductive detection loops. Train braking distance would determine the minimum distance from the crossing at which successful intervention in the train's operation would avoid collision with a stalled, disabled, or trapped vehicle. If a collision could not be avoided, intervention could still possibly reduce collision severity.

There are two major concerns with this application. One concern is a dramatic increase in warning/closure time of the grade crossing, required to provide for a train to come to a safe stop short of the crossing. This would dramatically increase the delay time to highway traffic from currently 20 to 40 seconds to approximately 2 to 4 minutes, thereby increasing the likelihood of highway user violations.

The second major concern is the possibility that motorists would learn to misuse this protective feature to intentionally cause trains to slow or stop by parking vehicles on the crossings. This might be done purely as vandalism or might be used in conjunction with criminal activity, such as theft of contents on stopped trains. Certain areas in the country have a real problem with this today, and the implementation of this system could provide an easy means to cause train stoppage, further compounding the problem. This misuse could also lead to increased delays for rail and highway traffic flows.

d. Warning System Monitoring

A remote monitoring system could notify the railroad dispatcher, signal maintainer, local police, and appropriate roadway authorities of a malfunction of the crossing warning system to promptly repair the system and/or warn highway users of approaching trains.

Remote monitoring can provide secondary benefits to highway traffic operations personnel. A highway traffic management center (TMC) could determine the activation status of crossing warning systems, permitting the TMC to track train movements and take action to alleviate the effects upon traffic congestion on intersecting and adjacent roadways. Possible responses might include temporary adjustment of traffic signal phasing and timing and the implementation of lane use and turn restrictions through dynamic lane assignment and variable message signs. The information could also be relayed to police, fire, and ambulance services, to facilitate routings to avoid blocked crossings.

e. ITS User Service #30 Highway-Rail Intersections (HRI)

There was an initial noticeable absence of railroad issues (such as the highway-rail grade crossing) in the development of the ITS architecture. With the inclusion of User Service #30, the importance of the highway-rail grade crossing (or highway-rail intersection) as an ITS traffic control element was recognized, and the way was opened for much broader railroad participation. An important long-term solution to reducing collisions between highway and rail vehicles at highway-rail grade crossings will be through the use of ITS, that is, when intelligent systems will be able to alert the highway user to the presence of a train and decrease the probability of highway vehicle incursions into the right-of-way of an approaching train.

The ultimate objective of the ITS in-vehicle warning system program is to design a system to warn motorists about the numerous dangers, congestion and road blockage along the roadways, including the proximity of emergency response vehicles, the presence of school buses, and advanced warnings of approaching trains. This multiple functionality will allow motorists to avoid hazards and utilize alternate routes. In developing such devices, both the highway and railroad industries need to participate and coordinate their efforts in standards development committees. The National Transportation Safety Board (NTSB) recently encouraged the development of ITS applications (*R-98-41,-42*) and strongly urged the active participation of the railroad industry in all aspects of the standards development process.

The NTSB recommended that the DOT establish a timetable for the completion of standards development for ITS applications at highway-rail grade crossings and act to expeditiously complete those standards. There is a need for the establishment of national standards for such things as: radio frequencies, auditory alerts, message codes, ITS protocol, and all communications that affect the grade crossing, and procedures necessary for maintenance, inspection, and testing of ITS systems. DOT is providing technical assistance and financial support for the development of ITS standards by the national standards development organizations.

f. Recommendations

The RSAC recommendations are:

- The FRA and the railroads should continue to work with the ITS program to ensure that standards are developed for User Service #30, including appropriate interfaces and messages (e.g., train locations, directions, speed) between PTC and Intelligent Transportation Systems.

- The Federal Highway Administration and ITS America should be encouraged to foster deployment of in-vehicle systems capable of appropriately utilizing data provided through PTC or other systems to warn motor vehicle drivers of the need to yield to trains at highway-rail grade crossings.

- The FRA should promote prudent research and development to enhance the potential for ITS and allied technologies to advance safety at highway-rail grade crossings by other means, such as warnings to trains of crossing system malfunctions, and detection of large vehicles improperly occupying crossings.

IV. Risk Reduction Potential

A 100 percent risk reduction cannot be assigned to any individual risk countermeasure. There are risks assciated with the adoption of any new technology. Some risks are uncovered because of cost, or system design. Other risks occur because of mistakes made in the implementation. Achieving safety is a combination of risk reduction strategies, targeted at specific safety concerns. Trying to address all possible risk areas leads to an inability to ever settle on the system requirements. It is better to address the primary risks and achieve incremental safety improvements.

A. Accident Statistics Review

A large accident database of candidate PTC Preventable Accidents (PPAs) was reviewed by a team composed of RSAC members, and a judgment made on whether each accident was a PPA or not. These judgments were based on the generalized capabilities of the four PTC concept levels discussed in chapter 2.

The team, called the Accident Review Team (ART), reviewed accidents from a data set of about 6,400 accidents. This data set was compiled from over 25,000 accidents reported to the FRA from 1988 through 1997. The 6400 accident data set was reviewed in detail and the results of that review are shown in this report.

A review of the requirements for reporting accidents identified 63 causal factors of accidents that are potentially PTC preventable. The RSAC PTC Working Group assigned the ART to identify the PTC preventable accidents in which those causal factors were present. The ART was composed of representatives from railroad management, labor and FRA and had many years' experience in railroad operations, signal and train control systems and research and development. In some cases, members of the ART were on site at the time of the accident investigation.

In its review of many reports, the ART had some problems in properly concluding what happened because data fields were in conflict, missing, insufficient or contained incomplete information. When necessary, further information was obtained from other sources. In every case, a final decision on the classification of an accident was achieved by consensus.

The determination that an accident was a PPA, a non-PPA, or some other category resulted in a notation being made in the database under the appropriate design concept. Certain accidents were identified that: might be preventable by that category of PTC; may/will have the cost of the accident mitigated by a category of PTC; involve a track machine collision with another track machine that is not preventable with current technology but may be preventable with future technology; or involve collisions between trains and track equipment outside the limits of the track equipment's authority. The following symbols were used to identify the capability of PTC to prevent or mitigate accidents and are noted under the four PTC design concepts.

- C Y - Preventable by PTC
- C N - Not preventable by PTC (not included in the table)
- C M - May be preventable by PTC under certain circumstances
- C R - PTC will mitigate the cost of the accident
- C S - PTC may mitigate the cost of the accident
- ! O - optional protection from collisions with trains when the track equipment is outside the limits of the track equipment's authority
- C W - Track machine collision with another track machine - not preventable with current technology

The Accident Review Team completed an evaluation of about 6400 accidents that were determined from previous analysis to be "likely" PPAs. The result of that analysis is shown in Table 1. At each level there are a portion of the 6400 accidents that are PPAs, and a portion that fall into the categories of m, r, s, o, & w.

Table 1. PTC Accident Review Summary - PPAs[26]

Level	Category y	Category m	Category r	Category s	Category o	Category w	Total
4	685	259	1	7	23	65	952
3	627	26	0	5	14	15	658
2	568	19	0	3	14	15	590
1	393	82	0	0	14	15	475

The m, r, and s categories represent some diminished risk of a PTC accident, rather than absolute "prevention." The o and w categories represent a potential future capability to prevent collisions between track equipment working under the same authority, and should not be considered to have any risk reduction due to PTC as defined.

An accident identified as category m or s in levels 1, 2, or 3 maybe classified as either a y or r at a higher level. An accident identified as category m in level 4, 3 or 2 may not be classified as a m in a lower level.

It should be understood that Table 1 does not represent the universe of PTC preventable accidents that occurred in calendar years 1988 to 1997, inclusive. Only a preferred number of accident cause codes were selected to identify candidate PPAs for review by the ART. It is probable additional accidents that are or may be PPAs reside under cause codes that were not reviewed by the accident review team.

[26]Total is sum of y, m, r and s. Categories o and w are not included in the total.

B. Corridor Risk Assessment Model (CRAM)

1. Background

In its 1994 Report to Congress the FRA concluded that "..while a *universal* PTC requirement could not at present be warranted on the basis of cost and safety benefits alone, the benefits of PTC may justify the costs in certain corridors with certain characteristics, including the presence of passenger trains, hazardous materials or higher levels of congestion...FRA will continue to support PTC research, development, and implementation in a number of ways.".[27] The FRA determined at that time to undertake certain actions to invest in the development of PTC, including to "initiate development of a risk analysis model to guide determination of priorities (among major freight rail corridors) for application of PTC technology."[28]

In 1995 the FRA requested that the United States Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) determine the feasibility of developing a corridor risk assessment tool for railroad operations based on a geographical information system (GIS) platform. The FRA was interested in using this analysis tool to determine if the deployment of positive train control (PTC) could have beneficial safety impact on specific operational freight and/or passenger railroad corridors of the United States intercity railroad network.

The Volpe Center determined that development of such a tool with GIS layers gathered from existing data bases of FRA track configurations, census population densities, etc., with added layers developed from inputs such as the Interstate Commerce Commission's waybill sample, was possible. In 1996, the Volpe Center began to build the GIS database and to conduct the related analysis effort, based on the FRA's definition of what PTC functions were and the existing prototype systems. With the GIS database and a definition of PTC preventable accidents provided by the FRA subject matter experts, an analytical model that described risk of PTC preventable accidents based upon geographical characteristics was developed. The preliminary results and conclusions were presented to the FRA and the RSAC in June 1997.

When the RSAC PTC Working Group was formed in September of 1997 this effort was offered to the group by the FRA as a possible tool to assist in their risk analysis. The Implementation Task Force of this Working Group was briefed on the background and status of this analysis effort, referred to as the Corridor Risk Assessment Model (CRAM). During late 1997 and into 1998 this Task Force and individual railroads provided input and direction to the ongoing modeling effort. Four areas of the modeling effort were addressed; 1) the definition of PTC functions; 2) the selection of PTC preventable accidents, 3) the data to be used as the basis for exposure measure – total train miles and million gross tons of traffic for each railroad; and 4) the definition of operational corridors that were to be analyzed. As noted in Section IV., A. of this report, p. 44, the Working Group formed an Accident Review Team (ART) that identified

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[27]FRA 1994. Report to Congress Communications and Train Control, p. v
[28]Ibid. p. 78

accident causes and specific accidents that could be used as input into the regression analysis for predictive purposes. The AAR and participating railroads, freight, intercity passenger and commuter, provided additional information on network flows of their respective operations.

a. Model Development

Railroad accidents are rare events, averaging only one FRA reportable train accident for every 264,000 train miles operated (FRA Railroad Safety Statistics – Annual Report 1997 – September 1998, Chapter 1, Page 1, Table 1-1). Reporting thresholds in 1997 were $6,500 (this number is adjusted periodically for inflation) for rail track or equipment and any accident resulting in an injury or fatality. The subset of accidents that may be reduced by PTC is even fewer. However, PTC preventable accidents occasionally are of very high consequence with lives lost and injuries or major equipment damage. The CRAM was developed to support the analytical activities of the FRA's Office of Safety in this low-probability but potentially high-consequence arena of accidents. The model was developed to determine what operational and track layout characteristics are statistically significant in PPAs and whether required implementation of PTC systems could reduce the accident risk potential on specific rail corridors. The model provides an estimate of PPA rates for defined corridors of the Class I intercity railroad network and the average consequences of those accidents. The model does not provide a system level risk analysis of individual PTC technologies or designs.

Initially the accidents for study were determined by using a group of FRA subject matter experts to determine applicable accident cause codes and the degree of effectiveness of a PTC system to prevent accidents in these cause code areas from the FRA's Railroad Accident Information System (RAIRS) database. RAIRS is the FRA's official database describing accident occurrences and outcomes, and provided the input for accident-related data used in the development of the CRAM. The data years 1988 to 1995 were used and the waybill sample were used to generate network flow data. These data layers resulted in the first model results known as CRAM I. The review of the 1988 to 1995 RAIRS data identified 570 accidents for historical plotting on defined corridors and 897 accidents for the regression analysis. Subsequently, the ART was formed and it reviewed in detail each potential PPA in the 1988 to 1997 RAIRS database, however, only 1988 to 1995 was used for the CRAM development. The data from 1996 to 1997 was reserved for use in model validation. This review (1988 to 1995 only) resulted in 819 accidents, of which 814 could be assigned to a geographic location for historical plotting. Of those 814 accidents, 678 had complete data enabling them to be used in the regression analysis. The new PPAs and network characterization data, including location-specific train counts and gross tons per year from the railroads were then added to the GIS platform and a second iteration of regression was done. The new model is referred to as CRAM II.

The theory behind both CRAM I and CRAM II is to estimate the safety benefits of PTC by relating the historic occurrence and consequences of accidents that may has been prevented by a PTC system to specific track features and traffic. The model as constructed will estimate the rate at which these accident and their consequences were likely to occur by corridor. The model does not account for any changes in operating rules or other structural changes (e.g., locomotive crashworthiness) that could impact the occurrence and consequences of these accidents.

The determination of PTC system functions, and their effectiveness in accident reduction were made in conjunction with FRA Office Safety and independent subject matter experts under CRAM I and by a team (ART) of the Implementation Task Force under CRAM II. The assumptions of what constitutes PTC systems is covered in Section III of this report. These assumptions were used by the ART in their analysis of the RAIRS data. Both CRAM I and II are accident forecasting models to predict future patterns of PPAs based upon historical data. Analyses using both the model based on historical data in combination with significant operational and track attributes, and simple plotting of historical data have been developed. The main intent of these analyses was to determine corridors that are most likely to benefit from some form of PTC implementation.

b. Risk Analysis Framework

This risk analysis has included the estimation of both PPA probabilities and consequences. Certain system characteristics such as signaling and train control method, operational speed, track class, horizontal and vertical curvature, control points and number of tracks were studied to determine which ones had statistical significance relative to contributing to and thus aiding in predicting the probability and consequence of a PPA. To assess the risk impact of a PTC system three aspects of the accident occurrences are considered important: accident location; accident cause; and accident outcome.

First, track and environmental aspects surrounding track describe the location of the accident that are used as factors in the probability calculation. The accident rate is calculated based upon the characteristics of the rail network, and therefore the characteristics of track which promote the occurrence of an accident must be ascertained for the whole network.

Second, the cause of the accident determines whether or not it is included in the set of PPAs. Starting with FRA RAIRS accident cause codes, the Accident Review Team developed the group of accidents for further study.

Third, the RAIRS database shows that PPAs were slightly more severe than the average accident, and as a result, only PPA accident outcomes were employed to develop the consequences portion of the model.

c. Geographic Data used for the Analysis

The geographical information system (GIS) used in this study facilitated the analysis of the rail specific characteristics in the prediction of risk and distinction of risk between corridors. This network thereby provided the basis for the accident rate calculation; the probability portion of the risk analysis.

For this study GIS data were gathered from the FRA 1:2,000,000 scale rail database, the FRA 1:100,000 rail database (developed by Oak Ridge National Laboratory for the FRA), and the

Volpe Center 1:2,000,000 and 1:100,000 rail databases. Detailed rail survey data available from a previous study was also used to add important attributes to the GIS platform. The resulting GIS platform is at a 1:100,000 scale to provide the required detail necessary for corridor analysis and consists of a fixed segment rail database that incorporates all the location-specific data from the various sources described above. Location specific data includes; switches, number of tracks, horizontal curvature, vertical grade, maximum speed, signaling system type, method of operation, route identifier, and population within certain distances from the track. This database consists of approximately 8,000 segments that are used for the construction of link-based calculations of risk and consequences. Links are defined in terms of control points as denoted by the presence of an interlocking switch. Link endpoints are also created at locations where Amtrak and commuter rail station stops are located, the number of tracks change, method of operation changes, or railroad owner changes.

d. Definition of Corridors

This analysis sought to describe the potential differences among operational rail corridors by applying the results of the CRAM model. The FRA provided the initial definitions of the corridors. These corridor definitions were adjusted by the railroads in some cases to reflect current traffic patterns. In general freight and intercity passenger rail corridors run between major cities. Commuter railroads are shown as unique corridors. Corridors with joint use are analyzed from the perspective of the owning railroad. As a result, 183 corridors were identified with an average length of 482 miles, the shortest corridor is 61 miles and the largest corridor is 1,922 miles. These corridors represent the dominant freight and passenger routes in the United States and 78 percent of the total route miles in the United States.

e. Historical Data Analysis

The historical location and consequences of PTC preventable accidents were calculated and assigned to corridors. Using this method provides a straightforward description of the historical costs of accidents that could have been prevented by PTC. However, this methodology is limited in that the analysis does not describe the factors that contribute to risk, or provide a basis for accident prediction. The modeling effort was developed to address these issues.

It was useful to identify the historical trends in the occurrence of PTC preventable accidents both to improve our understanding of the patterns of accidents and to inform ourselves as to the magnitude of accident costs and potential benefits from implementation of some type of PTC technology.

The development of the CRAM II model included the new data and inputs from the railroads and labor. The RSAC Accident Review Team provided the Volpe Center with a more up-to-date list of PTC preventable accidents for the years 1988 to 1995. The ART identified 819 accidents that were PTC preventable (yes category) or partially preventable (maybe, r, or s categories) using the highest (level 4) PTC system (see Table 2 for a summary of the ART review results).

Collisions accounted for 245 of these accidents, in which 51 people were killed and 447 were injured. The level 3 system, which assumed a lower level of functionality of PTC systems, was thought to have been able to prevent or partially prevent a total of 541 accidents, 230 of them collisions. Interestingly, these collisions included the same number of fatalities, and accounted for 441 injuries. At the PTC preventable levels 2 and 1, the total number of accidents classified were 478 and 384, and the number of collisions were reduced to 219 and 200, respectively. However, even at the lowest level of PTC functionality the total number of fatally injured in collisions remained 51. The level 2 system was thought to have potentially prevented 423 collision-related injuries, and the level 4 system 400. This outcome reinforces the perception that most fatalities and injuries are the result of collisions, which PTC at any level is designed to address.

Derailments are the second general category of accidents thought to be addressed in part by PTC. Derailments accounted for 420 of the 814 (52 percent) accidents at the highest PTC level, and dropped to 198 (37 percent) of the 541 accidents in level 3. At levels 2 and 1 they represent 32 percent and 28 percent respectively.

Other accidents (not collisions and derailments) are included in the group of PTC addressable accidents, including those involving roadway workers and equipment. At PTC level 4, 149 accidents were thought to be preventable or partially preventable, accounting for 4 fatalities and 7 injuries, this number dropped to 113 for level 3, representing 2 fatalities and 5 injuries, 105 for level 2 and 75 at level 1, which includes 3 fatalities and 5 injuries.

Table 2: Summary of PPAs 1988 to 1995 (including "maybes")

Level 1

Category	Total	Fatalities	Fatalities RR	Injured	Injured RR	Dollar Damages (Millions)	Evacuations
Collision	200	7	44	60	338	$109.80	783
Derailment	109	0	0	152	22	$26.85	267
Other	75	0	0	5	29	$7.07	36

Level 2

Category	Total	Fatalities	Fatalities RR	Injured	Injured RR	Dollar Damages (Millions)	Evacuations
Collision	219	7	44	60	361	$112.01	811
Derailment	154	0	0	152	25	$30.95	311
Other	105	0	0	5	31	$7.62	55

Level 3

Category	Total	Fatalities	Fatalities RR	Injured	Injured RR	Dollar Damages (Millions)	Evacuations
Collision	230	7	44	60	381	$118.97	836
Derailment	198	1	0	154	35	$37.11	372
Other	113	0	2	5	32	$8.02	55

Level 4

Category	Total	Fatalities	Fatalities RR	Injured	Injured RR	Dollar Damages (Millions)	Evacuations
Collision	245	7	44	60	387	$119.67	838
Derailment	420	44	6	247	71	$87.86	706
Other	149	0	4	7	48	$11.80	151

All PPAs

Category	Total	Fatalities	Fatalities RR	Injured	Injured RR	Dollar Damages (Millions)	Evacuations
Collision	245	7	44	60	387	$119.67	838
Derailment	420	44	6	247	71	$87.86	706
Other	149	0	4	7	48	$11.80	151

fatalities/injuries = all except for RR employees
fatalities RR/injuries RR = any railroad employees (on or off duty)
evacuations = number of people evacuated in an incident

The trends in the derailment category indicate relatively infrequent low-consequences events, whose greatest potential hazard is in the possibility of the release of hazardous chemicals requiring an evacuation. Seventeen of four hundred twenty derailments resulted in evacuations; the average number of people evacuated was approximately 420 per incident. Two incidents resulted in over 1000 evacuations. One derailment, included in the group of accidents thought to be possibly preventable by the highest level of PTC system, accounted for 47 fatalities. This accident is not consistent with the general trend of the consequences of PTC-preventable derailments being less than collisions, but it identifies a source of risk. The historical data can only answer part of that question. To understand the total risk potential for the United States that might be addressed by PTC, a more formal assessment of the hazards other than through the use of CRAM would be required.

To systematically compare corridors with respect to their historical accident experience, the costs of accidents were assigned to each one, using a cost assignment methodology. A full description of this cost assignment methodology appears in the Economics Section (Section V.-C, p. 69). Using this methodology, costs were assigned to each PTC preventable accident, using the scale \$2.7 million per fatality, \$100,000 per employee injury, \$55,000 per passenger injury and \$500 per evacuation. Dollar damages to track and equipment were included as reported on the RAIRs accident reports. To reflect additional unreported costs for repairs, delays and equipment damages, specific costs were assigned to the cost of accident emergency response, rerailing derailed equipment, and the loss of hazardous materials . Using these numbers the average PPA cost \$1.10 million, ranging from the lowest accident cost of \$10,266.00 to the highest of \$8.581 million). The result of the historical cost assignment is illustrated in Figure 1.

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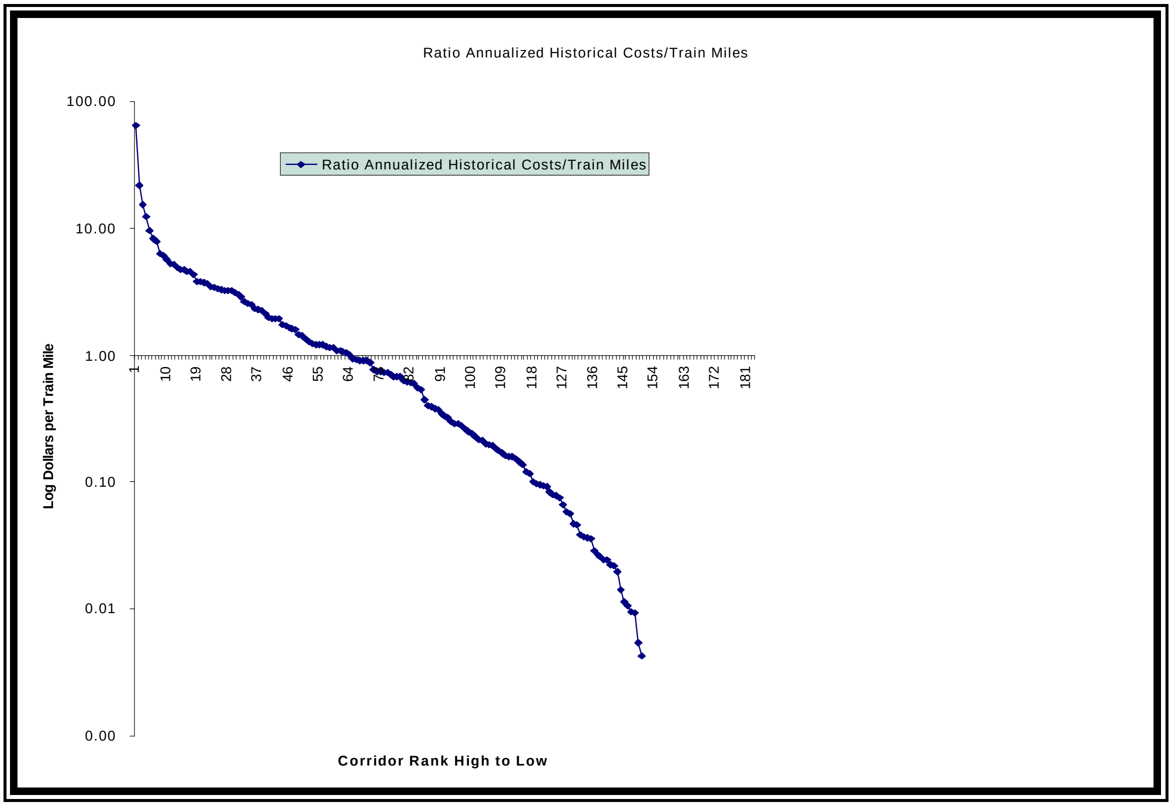

Figure 1. Historical Accident Costs per Train Mile All Corridors

The historical costs of PTC-preventable accidents are concentrated at a handful of locations experiencing catastrophic PPAs. However, that concentration does not necessarily imply that future PPA costs will be concentrated at the same locations. To predict the future PPA locations, one must employ a model that relates network and link characteristics (e.g., curvature, train volume, etc.) to PPA experience. That is what CRAM does.

The historical data simply represent the accident experience that provided the basis for this analysis, however, and does not provide us with a model. For that reason the results shown in Figure 1 must be compared to those shown in Figure 2.

2. Model Development

A regression analysis is generally used to understand how different factors describing a system relate to one another. Since this analysis focused on the identification of locations where PTC preventable accident risk was significant enough to warrant implementation, the methodology was designed to identify characteristics of various locations that seemed to contribute to risk. The quantification of the contribution to risk of factors such as method of operation, signaling, speed limits, the number of tracks and characteristics of the volume of passenger and freight traffic on the network were used to develop a tool that would make distinctions between corridors based upon PTC preventable accident risk.

Models were estimated using a regression methodology that allows the dependent variable to be the number of PTC preventable accidents that happened at a location. The independent variables used to understand the frequency of these accidents were the total trains per year at the location, the curvature, switches, number of tracks, type of control method, and speed at the location. Models were estimated for all four levels of PTC preventable accidents. The results of the model can be used to create an estimate for any location where there is complete data on these independent variables, provided the conditions represented by the model remain the same, and the accident trend on each corridor for the years analyzed is constant.

One of the most important components of the analysis is the input data. In this analysis, the critical variables, namely the selection of PTC preventable accidents, and the freight-flow data and the passenger flow data, were provided by the railroads and representatives of labor unions. Network variables that describe track characteristics, control methods and speed, were collected from published railroad descriptions, track charts, schedules, etc. Some PPAs occurred where freight or passenger flow had not been provided by the railroad. However, the railroads did provide that data on accident reports to the FRA at the time that those accidents occurred. In these cases, track density reported by the railroads on the RAIRS report were used in the analysis.

a. Estimation of Accident Consequences

If it can be assumed that accidents will behave in the future as they have in the past, then the historical consequences of accidents can be used to describe the likely consequences of future accidents. For this analysis, it is most useful to create a single unit with which to express risk. This is accomplished by quantifying the costs of accidents in dollars. Dollars are used to express the government's estimate of society's willingness to pay to avoid fatalities, injuries, track and equipment damages and evacuations, and the costs or societal value assigned to emergency response, delays, and other effects of accidents.

b. Model Specification

The PPA accident model was developed using a regression technique that describes the relationship between location-specific factors and the occurrence of PPAs. The specific method employed is called *Poisson* regression after the person who first described the basic concept. This method is used to estimate a model in a way very similar to a linear regression model in cases where the concern of the analysis can be described as an event or collection of events (such as accidents). Most importantly, the analysis applies to events that occur over time.

The events in this analysis are defined as the number of PTC preventable accidents that have occurred in each location during the eight year analysis period. It is assumed that these events are *Poisson* distributed, not normally distributed, events.[29]

The modeling objective is to design a function that provides a consistent estimate of the average number of accidents per year. The model is constructed assuming that the average number of occurrences per time period has both a random and a systematic component. Further we assume that the random component behaves in a manner that is consistent with a Poisson process, and that we can describe the systematic component of this process by identifying common factors surrounding the accident occurrences. Since this analysis is focused on identifying locations that have a potentially higher risk experience this analysis has sought to describe the common *geographic factors* to all accidents, based upon the best available data describing the locations at which those accidents occurred.

The major feature of this model that is different from any standard linear model is that the dependent variable is a discrete variable (i.e. the accident count per year). The independent variables in this analysis, in a way similar to the linear regression counterpart, can be continuous, discreet, or transformed variables (such as the natural log of a value). The explanatory variables have been selected to allow us to identify how location-specific variables might have contributed to the occurrence rate of PPAs, even though we are aware that some random component of this process still exists.

c. Model Selection

The process of model selection involved model estimation, validation, and re-estimation. In the construction of the CRAM II model, eight regressions were estimated to reflect the different datasets that result from the sieve implied by the PTC preventable criteria. Accidents have been rated as to their preventability by each of the four levels of PTC, and also the degree of their preventability (either complete or partial). As a result, we are confronted with eight possible datasets, four levels of PTC and two datasets (those that include yeses and maybes, and those that only include "yeses") for each PTC level. To reflect theses differences a separate regression analysis was constructed for each dataset. Regressions were estimated for all PTC preventable accidents, excluding grade crossing accidents, where the dependent variable expressed the number of PTC preventable accidents weighted by exposure:

<u>N / (length (miles)) for each link;</u>

and the independent variables were allowed to include any of the following: the natural log of

[29] This means that tests of normality, as would apply to a "normal" or "Gaussian" distribution are not applicable to these events. Therefore, the estimation methodology must reflect the underlying assumptions of the *Poisson* distribution.

the total number of trains on the link (the sum of passenger and freight trains), the square of the natural log of the number of trains on the link, a variable (equal to 0 or 1) for whether the total number of parallel tracks was one or greater than one, a variable equal to the total number of switches on the link, a variable indicating what the highest maximum speed for the location was, a variable that indicated what percent of the length of the link was under control method; Auto Train Stop, Cab Signaling, CTC, or Dark Territory, and a variable indicating whether there were any curvatures recorded for the link.[30]

Further research might help draw out the analytical distinctions and inform policy discussions regarding differences between freight and passenger trains in both the historical accident data and the estimates of PTC preventable accidents. This research would clarify at least the following three distinguishing characteristics between freight and passenger train circumstances in the context of PPAs:1) passenger and freight trains operate differently with respect to speeds, programmed stops, and service braking characteristics; 2) passenger trains are more likely to be concentrated on highly maintained and multiple track, and on lines with cab signals; and 3) passenger train accident consequences are sometimes greater because of injuries and casualties to passengers (in addition to train crews and/or bystanders). Implications of these differences could be analyzed in the historical information and reflected in estimates of future PTC economics.

3. Results

The analysis sought to evaluate how all four different PTC levels might have affected risk on all of the predefined corridors. Since some accidents were thought to be "completely" preventable, and others had qualities that suggested that there was uncertainty as to their complete preventability, it was desirable to reflect this in the analysis as well. Of the available options for comparing these different accident categories, the most straightforward is to estimate the same model on all datasets. Given four PTC levels and two types (preventable and "maybe preventable") as noted previously, eight regressions were required.

In each case the model makes the best possible association of the independent variables with the number of accidents that have occurred on each segment for which those variables have been described. In this analysis there are 8001 geographical segments that have been characterized with respect to the important explanatory variables (train counts, speed, etc.). The model provides an estimate of the number of accidents that may happen on that segment

[30] Models were estimated using the statistical analysis software program, SAS, logistic regression program, using a stepwise technique. The logistic regression program permits one to estimate the exponential form of the regression equation. While this is a regression technique, it is distinct from linear regression in that the form of the estimated equation for a given link is expressed as:

$$\frac{E(N)}{Exposure} = e^{(a_{0_o} + a_1 * (\log cars) + a_2 * (\log^2 cars) \ldots a_k x_k)}$$

where N, the number of accidents on the link is Poisson distributed with expected value equal to E(N) and exposure is the length of the link.
The exponential equation contains any of the variables that were selected by the forward stepwise regression. The criteria for entry was significance at the 0.05 level. The procedure continues to include variables, one at a time, until no other variables meet the criteria.
Using only derailments and collisions either with trains or roadway worker equipment, models were estimated for all PTC accidents, using the control method as a variable in the regression. The performance of the model was evaluated strictly on its ability to predict the "correct" number of accidents in the dataset upon which it was estimated. Inclusion of additional explanatory variables continued until the final model produced the "best" performance.

based upon the accident experience for the entire network, and the similarities between the locations where accidents have occurred.

These results must be interpreted as the collection of the most influential factors in the determination of the occurrence of these PTC preventable accidents of those variables that were included in the model.

In Table 3 (Results) the resulting parameters for each regression based upon these datasets is presented. In column 1, the name of the variable appears. Column 2 refers to All PTC preventable accidents (including maybes) at level 4. This is the largest dataset (678). The regression parameters for variables that were significant in the stepwise regression can be read looking down that column. Likewise each successive dataset appears in the following columns.

Table 3. Results

	Yeses and Maybes				Yeses Only			
Parameter	**PTC Level 4**	**PTC Level 3**	**PTC Level 2**	**PTC Level 1**	**PTC Level 4**	**PTC Level 3**	**PTC Level 2**	**PTC Level 1**
N	678	468	420	344	489	442	402	274
Intercept	-13.0649	-13.8610	-14.4937	-14.6979	-13.9973	-14.1664	-14.5086	-15.0980
log trains	ns	ns	ns	ns	ns	ns	ns	
log trains squared	0.0256	0.0306	0.0345	0.0324	0.0297	0.0319	0.0340	0.0336
multitrak	0.4403	0.3714	0.3856	0.4204	0.4167	0.3829	0.4035	0.4727
ptrnrat	ns	ns	ns	ns	ns	ns	ns	ns
switches per mile	0.0495	0.0555	0.0545	0.0522	0.0539	0.0545	0.0545	0.0522
curves per mile	ns	ns	ns	ns	ns	ns	ns	
anycurve	ns	ns	ns	ns	ns	ns	ns	
lwavcurv	0.00198	ns	0.00170	0.00235	0.00166	0.00140	0.00179	0.00293
autopct	-0.5404	ns	ns	ns	ns	ns	ns	
sigpct	-0.4719	ns	ns	ns	ns	ns	ns	
lwaspeed	-0.0121	-0.0136	-0.0117	-0.00980	-0.0119	-0.0130	-0.0119	-0.00991

N = number of accidents

The final set of explanatory variables input into the stepwise procedure included :

intercept: a non-zero y-axis coordinate used to fit the regression equation

logtrains is the (natural) log of the number of trains on the link (this is based on a combination of waybill sample and FRA flow data)

multitrak is = 0 for single track territory and = 1 for all multitrack territory

ptrnrat is the ratio of passenger trains to total trains

anycurve is a binary variable indicating whether any curves existed on the link

Lwacurv is the length weighted average curvature for the link

autopct is percent of segment miles under cab or auto train control

sigpct is percent of segment mile under signalized control but not auto

lwavspeed is the length weighted average speed for the territory.

ns = variable not found significant in the regression

a. Interpretation of Regression Results

The regression results have been used to create an estimated number of PTC preventable accidents per year for all of the segments that had complete data on the rail network. Each location for which we possessed complete data, such as the train counts, curvature, speed, passenger train ratios, etc. were included in a calculation of the expected number of accidents per year using all of the 8 regression models. The results allow us to make comparisons between segments and to aggregate these segments into corridors and thereby compare corridors on a consistent and uniform basis. Corridor analyses are simply the aggregation of segment analyses. Thus this tool enables the development of "what if" scenarios for comparative risk analysis.

b. PTC Preventable Accident Forecasts Using Eight Regressions.

The eight regression analyses were used to create an estimate of the expected number of accidents for each link in the analysis, and then aggregated for each corridor. A cost estimate was created using the average consequences for the largest dataset (819 PPAs), including five accidents not located and thus not included in table, and the companion dataset for that one which excludes the "maybe" accidents (568). Using these two datasets a "high" and "low" level of consequences estimates could be made and applied to the regression results (see Table 4).

The consequences estimates are based upon aggregate averages for freight or passenger trains, and applied to each link weighted by the ratio of total passenger and freight trains on the link. For instance, it assumes that the average number of fatalities per passenger train accident is equal to the average number of fatalities per PPA passenger train incident in the database. Then for any individual link, the estimated accident rate is multiplied by the fraction of traffic that is passenger traffic, and multiplied by the fatality rate to obtain the estimated number of passenger train fatalities predicted for that link. In this way each of the 8001 links in the model that had complete data for forecasts were included in the estimate of consequences.

Table 4. PPA Consequences (averages over all accidents)

Passenger Train Costs	**Average Fatalities per Accident**	**Passenger Injuries**	**Employee Injuries**	**Track Damages**	**Equipment Damages**
HIGH	0.9483	3.3621	2.0517	$32,107	$493,515
LOW	0.1509	1.9245	1.9434	$19,885	$323,356
Freight Train Costs	**Average Fatalities per Accident**	**Non-employee Injuries**	**Employee Injuries**	**Track Damages**	**Equipment Damages**
HIGH	0.0938	0.2285	0.7031	$26,949	$265,906
LOW	0.0657	0.1564	0.5125	$26,313	$222,633

Employing the same cost assignment methodology used to produce historical corridor rankings, each corridor was ranked according to its predicted corridor risks per train mile. The results of these rankings are depicted in Figure 2. They indicate that some corridors have significantly higher risk than others, but that the majority of corridors are not significantly different from one another on the basis of risk.

There are some major differences in the average costs and expected rates for fatalities and injuries between the high and low estimates, most notably the parameter on expected passenger train fatalities is 84 percent lower in the low case than in the high case (0.9483 per incident versus 0.1509). Due to this disparity, it is important to show not only the range of values using the eight regression methodologies, but also their sensitivity to the resulting benefit assignment method.

The graph shown in Figure 2 represents all of the estimated and the average of the eight estimated total benefits per annual train mile for all corridors (for which forecasts could be estimated) and the distribution around those estimates.

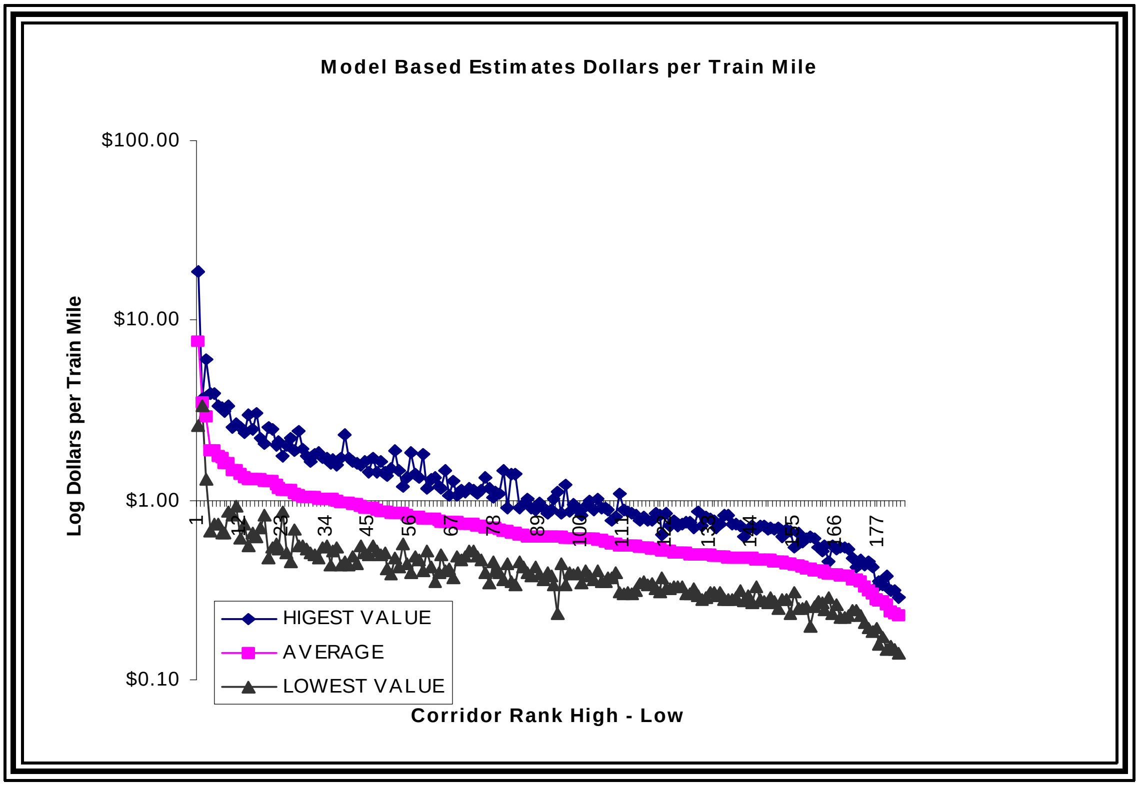

Figure 2. Average, High and Low Estimated Values for Dollars per Train Mile all Corridors

4. Potential Future Uses of the Corridor Risk Assessment Model

Using the highest level of PTC, the model indicates that the total train flow, the number of tracks, and the number of switches and curves per mile contribute to increases in the expected number of accidents and that the presence of a train control method higher than dark but lower that automatic train control will reduce that risk. In addition, two other factors contribute to lowered risk, the average length of curves at a location and the average maximum allowable speed. Since the model is estimated by combining all of these factors to create an estimate of risk for a given location, it is most useful to apply the regression formula to each corridor and compare the predicted number of accidents for each one.

The FRA plans to apply this new analysis tool to determine if a corridor approach to PTC implementation is appropriate, and as an evaluative tool for specific corridors. Several corridors in the United States such as Chicago to St. Louis, Chicago to Detroit and Seattle to Eugene are undergoing train control, operation and/or equipment changes as part of train control and passenger equipment deployment efforts under the FRA's Next Generation High-Speed Rail Program. FRA wants to ensure that the risk potential in some of these operations is well understood and whether improved train control systems can reduce the risk at an affordable cost.

In addition, the FRA intends to apply the GIS platform of layered databases to conduct other studies of accident trends and safety enhancement measures for topics ranging from grade crossing safety to hazardous material movements.

5. Conclusions

The point of this analysis was first to determine whether there was a methodology that could distinguish among geographic locations based upon risk. The objectives were to develop a comprehensive model of the rail network, including accidents, rail and operational features, and population characteristics. Using that platform it was the further mission of this analysis to use it to identify potentially fruitful locations for PTC system deployment.

The model was developed to enhance the policy-maker's ability to compare and contrast the risks posed by accidents (both those that are PTC preventable and others) and to create an estimate of the potential benefit of implementation of various policies. Since the model has no economic or logistical component, it is not a complete planning tool - i.e. it can only act as a pointer to locations that may potentially benefit from PTC implementation. Further analyses will be required to develop a true estimate of the net benefits of PTC implementation.

The analysis shows that we are able to make geographically based risk distinctions, and it allows us to compare extremely different localities because of our application of a uniform exposure measure - train miles. Further refinements of this exposure measure (such as night or daytime train miles, grade crossings per mile, etc.) will enhance our understanding of risk at each location.

In addition, the analysis pointed out that of the corridors studied the highest predictors of risk was the volume of traffic (as expressed by the log squared of the total trains per year.) The train control method was less important in prediction of the accidents of interest in this dataset than other factors.

It is interesting to note that since we have only a snapshot it is difficult to understand some of the parameters. It is counterintuitive to think that accidents decrease with speed limit increases as suggested by the parameter on length weighted average speed. However, we might reverse the description of this variable and say that we have imposed lower speed limits where accident risk is higher; if we had the luxury of looking at a time-series model we may notice that speed limit changes have taken place over time where risk factors were present. This highlights one of the limitations of the model in that it is not a time-series model and cannot account for trends.

Whatever its limitations, the model and its results should be taken as an input into the complex decision making process required to evaluate the myriad of PTC technologies and potential strategies for implementation. It is possible to adapt the tool to the individual needs of analysts and decision makers as they ask deeper and more specific questions regarding alternative technological innovations.

C. Approach to Safety Management Rules and Regulations

The Standards Task Force was adopted as a subgroup of the PTC Working Group in December 1997 for the following purpose:

- To facilitate the implementation of software based signal and operating systems by discussing potential revisions to the Rules, Standards and Instructions (49 CFR Part 236) to address processor-based technology and communication-based operating architectures.

The following task components were included:

- Disarrangement of microprocessor-based interlockings. What testing or other procedures and functions need to be performed in order to guarantee safe operation of a railroad interlocking control system that has been disarranged and subsequently restored to continue operation.
- Development of performance standards for positive train control (PTC) systems at various levels of functionalities (safety-related capabilities).
- Development of procedures for introduction and validation of new systems.

The Task Force could also consider conforming changes to related regulations (e.g., 49 CFR Parts 233, 234, and 235), as appropriate. The FRA members of the Task Force felt that the most logical way to fulfill the task requirements was to revise 49 CFR Part 236 to accommodate the new technology elements, and safety requirements of software-based signal systems. A draft text of revisions to Part 236 was made available to all Standards Task Force members for that purpose. Some members of the task force felt that Part 236 was a detailed and prescriptive type of regulation not suitable for the complexity of the processor-based and software-driven systems to which these new regulations would apply. These members also felt that it was time to develop performance- based standards using Mean Time Between Hazardous Events or an equivalent performance metric.

Several presentations were made by suppliers, railroads, labor, and government to educate members of the task force about what is needed for development of performance standards that could be used to regulate software-based systems. Recognizing the need to proceed with a representative safety critical assessment methodology for proof of safety of PTC and processor-based systems, the group tasked the University of Virginia (UVA) Center for Safety-Critical Systems to develop a representative Risk Management Tool Set. An interagency agreement to fund work to be performed by the University of Virginia was set in place. The work is expected to produce a risk measurement toolset for a safety-critical assessment process. A two-day seminar was given to the Task Force members by the University as part of this task. The development of this Risk Management Tool Set does not imply that other comparable methodologies could not be used.

Another area of investigation that the PTC RSAC Working Group is investigating is how to identify PTC information that can be communicated to highway traffic control/information systems. An ITS (Intelligent Transportation Systems) subgroup was established jointly with the Standards and Implementation Task Forces; the report of that subgroup is included in Section III, F, p.33 of this report.

Discussions within the Standards Task Force continue at the time of this report. There is a significant difference of opinion on the details of a revised Part 236. The scope of the changes has been a concern to many.

1. Axiomatic Safety-Critical Assessment Process (ASCAP)

An Axiomatic Safety-Critical Assessment Process (ASCAP) is under development at the University of Virginia Center for Safety-Critical Systems as a mathematical proof that is solved as a large-scale statistical simulation. It demonstrates the proof-of-safety-critical compliance to quantified risk exposure benchmarks for railroad freight and passenger train lines, subject to a statistical confidence level. The safety-critical benchmarks are expressed as accident risk exposures, which are normalized as either freight ton or train miles or passenger train miles that include variable train densities and average speeds. The risk exposure accident metrics are calculated as severity multiplied by the statistical likelihood of occurrence of an unsafe event, where a train is coincident in time and position with an unsafe event. Severity is defined as catastrophic, critical, marginal and negligible. Catastrophic is the loss of life and major assets, critical severity defines minor injuries and loss of major assets, marginal severity defines minor asset accidents and the negligible for incidental accidents.

The ASCAP mathematical formulation describes the capacity throughput performance of a train line as constrained by the safety-critical capability of the signaling and train control system to mitigate the hazards, which threaten the safe operation of the train line. ASCAP is structured as a large-scale train-centric hazard scenario statistical simulation that handles a train line of up to 100 freight, passenger, and short line trains operating in a complex multilayered signaling and train control environment. The risk exposures are calculated for each train operating on the train line and combined to provide the risk exposure of the total train line. An important feature of ASCAP is the capability to calculate statistically unsafe events that do not result in an accident as defined by the risk exposure metric. With this capability, ASCAP can provide a quantification of the train line reliability, availability, maintainability and safety (RAMS) for each train-centric unit and the total train line. The multi-layered signaling and train control systems can include dark territory, continuous signaling, intermittent signaling and communication-based Positive Train Control (PTC).

The ASCAP model formulation includes definitions, generally accepted industry standards, axioms (assumptions), hazards to be mitigated, the safety-critical protocol that mitigates the hazards, the proof-of-correctness of the safety-critical protocol, and finally, the proof-of-safety-critical compliance to established using quantified performance-based safety-critical benchmarks. A unique feature of ASCAP is the capability to include the railroad operating rules, dispatcher safety-critical behavior, and the safety-critical behavior of the train crew. The operating rules, dispatcher, train crew, track segments, switches, signal and processor-based equipment are all defined as objects. The safety-critical behavior of each object is defined with the calculation of an unsafe failure rate, which is in response to injected hazard scenarios. The definition of all of the traditional railroad safety-critical appliances as an object-oriented paradigm allows a detailed description of the signaling and train control system safety-critical behavior.

The hazard scenarios are selected as the list of hazards for which the most complex level of Positive Train Control (PTC) is required to mitigate. ASCAP, by selecting the most complex PTC hazard scenario list, is able to make safety-critical assessments of any signaling and train control systems implemented by the railroads. ASCAP will first be implemented as a pilot program in collaboration with CSXT to establish safety-critical assessments of dark territory operation, traffic control systems and communication-based train management (CBTM). An important outcome of the collaboration will be the safety-critical assessment of CBTM overlaid onto dark territory.

A wide range of analytical tools are used such as formal methods, fault modes effect critical analysis, Petri-nets, Markov models, fault injection simulations and statistical methods to establish confidence levels. The need to calculate millions of miles of train-centric operation subject to a statistical injection of hazard scenarios requires that ASCAP be formulated as distributed and parallel processing model which can be executed on supercomputer platforms.

V. Other Communications, Command and Control Requirements for the 21st Century: Potential Roles for PTC Systems

A. Implications for Traffic, Information and Asset Management, System Capacity, Service Quality and Profitability

1. Background

Signal and train control systems are generally justified by the need for an increase in capacity of train traffic over a route. Historically, Centralized Traffic Control (CTC) has been chosen to achieve the increase in traffic capacity. CTC, in conjunction with Computer Aided Dispatching (CAD) has been the standard on most railroads recently, where Automatic Block Signals (ABS) was the standard before. There are basically three reasons why a train control system needs to be upgraded:

- The load on manual dispatching is too high to run the required number of trains at the maximum track speed.
- Long blocks of space have to be allotted to trains, limiting the number of trains that can travel over a given route over a given period of time.
- The old train control system is technically obsolete.

2. New Technology

PTC systems, depending on their architecture, will increase both the track capacity and the amount of traffic that can be handled. This generally improves asset utilization of locomotives, rail cars and the track as well, allows for better service to customers, and improves profitability. It also improves the efficiency of train service crews by reducing train travel times and speed. Lines currently equipped with a train or traffic control system, generate certain of these benefits already. Some PTC systems architectures provide an overlay over the existing train control system already in place and the benefits are strictly limited to improvements in train safety. A stand-alone PTC system could replace the existing train and traffic control system. Therefore, deciding whether such a system would be chosen depends on the need for the replacement of the present infrastructure due to age, additional capabilities needed, or other criteria. Most existing signaled CTC systems have block sizes of about two miles, which for heavy freight traffic allows fleeting of trains with close spacing at track speed. This spacing also allows for efficient higher speed passenger train operation because of the shorter stopping distances of these trains.

Moving blocks, which can be achieved with communications-based train control may have some benefits on tracks where trains with significant differing train speeds operate. Slow-moving trains would waste capacity on a route originally designed for faster moving trains, requiring longer stopping distances. Electronically Controlled Pneumatic Brakes (ECP) may achieve similar efficiencies as moving block systems because it allows operation of higher speeds within fixed block systems due to shorter stopping distances.

Should the existing train control system need to be replaced for economic reasons, then a PTC level four type system could be chosen with various architectures. The control logic can be handled by a central office system, replacing existing CADs and office systems or by a distributed logic architecture where the logic is handled locally and possibly linked to an existing CTC office system. Both systems would be capable of moving block operation and either have new integral traffic management systems or use the existing ones. The decision to use a central office or distributed architecture is dependant on the investment needed in a communications infrastructure, the overall system reliability requirements, the ability to safety assure large scale safety critical office systems and the level of configuration management that is required for each system type. It is not expected that level four systems offer significant improvements over existing train and traffic management systems except for route segments where moving blocks can improve the real train capacity. Real train capacity requirement is defined as the actual time table required by the railroad's customers and present and projected traffic levels and not some theoretical capacity, which cannot be utilized. Railroads have so far not been able to identify many routes where moving block provides significant benefits over fixed block signal systems. It is anticipated though that a moving block PTC system would improve the capacity of track warrant controlled railroad and once the technology has been fully developed, it is anticipated that railroads would use the new technology, especially if the costs are equal or less.

B. Scale of Implementation Necessary to Return Benefits

1. Background

The key to the implementation of PTC is equipping a sizable portion of locomotives with train control units. Until a large portion is equipped, the old train control system has to stay in place. Running unequipped locomotives on a new system will degrade the operating efficiency. Overlay PTC type systems are not dependent on having a large number of locomotives equipped, since the underlying train control system is still in place. Equipped locomotives will merely improve the overall safety of the system, which is maximized when all locomotives are equipped. PTC systems will change in architecture and technology applied over time and it makes good business sense to take advantage of those advances. Therefore, the locomotive-based equipment has to be designed to a minimum interoperability standard. Since the basic functions that make up every PTC system will not change, they can be defined and made independent of technology.

Equipping locomotives and roadway workers' vehicles will be the most expensive part of the PTC system. Incremental installation of on-board units as new equipment is purchased or overhauled will eventually result in the majority of locomotives to be equipped. French National Railways (SNCF) experience shows additional safety benefits will be accrued with every locomotive equipped and every mile of wayside equipped. This probably is the easiest way to continuously improve safety and receive the benefits as the capital investments are being made. There will be cases where the amount of traffic over a route, the desire to maximize capacity, or the need for a high level of safety will make it beneficial to accelerate the installation of PTC units to locomotives. The economics will drive the rate at which PTC systems are implemented. There may be cases where the implementation speed will be driven by increased risk, such as high-speed passenger traffic.

2. Summary

Implementation of PTC systems will be driven by economics of the systems. Most systems generate safety benefits only. Others may have some other benefits in limited geographic areas with specific traffic requirements. Companies spend their capital where the most benefits can be achieved. For a railroad, most of the capital investment will improve safety and operating efficiency. PTC, like any other capital requirement has to compete for limited funds. This precludes equipping large sections of track with PTC at one time, but an incremental investment based on priorities driven by risk. These corridors may not necessarily be adjoining. Locomotives and roadway workers' vehicles will also have to be equipped incrementally, driven by risk and return on investment. Therefore, a technology-independent, interoperable on-board unit is a requirement.

C. Costs and Benefits of PTC Systems

1. Economics of Positive Train Control

No cogent public policy regarding Positive Train Control can be formulated until we know what the tradeoffs are. What benefits will PTC gain for us, and what will these benefits cost? The Implementation Task Force needed to review studies, such as the Corridor Risk Assessment Model, regarding where PTC may be needed.   The Implementation Task Force has also heard competing theories regarding what business benefits may be derived from PTC. To resolve these issues, the Implementation Task Force assembled an Economics Team, and empowered them to study these issues and make consensus recommendations.

The Economics Team included members of management, labor, commuter railroads, and the FRA. It was fortunate that one member of management, one representative of labor, and one representative of FRA on the Economics Team had been members of the Accident Review Team, which earlier had analyzed accident reports to determine which accidents were PTC-preventable.

2. PTC Benefits: Accidents Costs Avoided

The Team's first task was to assign costs to the accidents designated as PTC-preventable by the Accident Review Team. These costs were to be used as inputs for the Corridor Risk Assessment Model. The Corridor Risk Assessment Model measures the likelihood of certain occurrences, using a probabilistic model. It then assigns costs to these consequences in order to distinguish and prioritize among corridors. It may also be possible to estimate the expected consequences of these occurrences in a model using consequences as a dependent variable. In order to use either model we need to know the unit costs of various occurrences, such as fatalities, injuries, property damage and evacuations, the avoidance of which provides the direct **safety benefits** of PTC. It is desirable to estimate other costs, but the FRA accident report does not contain data on them. An example of such a cost is environmental clean-up. The Economics Team tried to limit the data on which its estimates relied to data on the Accident Reports, or otherwise in the CRAM database. The Economics Team was able to fashion several such estimates, and to provide some thought on others.

a. Fatalities

The first element on which the Economics Team reached consensus was on the willingness-to-pay to avoid a fatality, which the Team estimated at $2,700,000 per fatality. This number represents what society has been shown to be willing to pay for safety devices which will in the future avoid a fatality, and is a standard number used by all DOT agencies.

b. Injuries

The Economics Team also agreed to accept a value of $100,000 per employee injury avoided due to train accidents. The team considered the Accidental Injury Severity (AIS) scale, which DOT uses for comparisons of injury costs. This would imply an average injury on the low side of the interval between moderate and severe injuries, and uses a round number. There isn't much precision in this estimate.

Data from four commuter railroads indicates that their average payout per injury claim was about $35,000. This represents settlements and judgements. While the judgements probably reflect loss per claimant where the railroad was found liable for the injury to the claimant, there may have been injuries where the claimant was not successful. The settlements reflect the expected value of suits had they gone to trial, and reflect a reduction from the actual claim which is the risk that a claimant might lose were the case to go to judgement. From an economic standpoint who is liable for an injury is not relevant to the question of the societal loss caused by an injury. Further, the loss to society also includes the costs of administering and pursuing claims. Thus the fees paid to claimants attorneys, and the costs of defending and administering claims are also societal costs of an accident. If the average claimant received $35,000 it is not unreasonable to assume that the societal cost of an average passenger injury in real economic terms was roughly 50 percent greater, or about $55,000, a figure accepted as a consensus estimate by the Economics Team.

c. Equipment Damage

The Economics Team attempted to distinguish between the costs of equipment damage reported on the accident report and the actual loss to society of that damage. The FRA Safety Regulations require that the railroads report the depreciated book value of the equipment damaged if the equipment is destroyed. Otherwise, the railroads must report the estimated costs of repairs. The depreciated book value can be a poor estimate of the societal value of a car. A much better estimate is provided by concepts such as Economic Limit of Repair (ELOR).

Several major freight railroads utilize a concept and methodology called Economic Limit of Repair (ELOR) or Maximum Allowable Expenditure for Repair (MAER) to determine the value of existing equipment, particularly equipment being considered for repair or upgrade. Where estimated repair costs exceed the ELOR or MAER, the equipment is typically scrapped or placed in a heavy bad order status rather than repaired. The ELOR methodology typically considers contribution to revenue, replacement cost, salvage value, service life, repair life, and repair cost.

FRA incident reporting requirements dictate that equipment damage costs be the repair estimates for damaged cars to be repaired and depreciated book value for destroyed cars. However, the PTC Economic Team agrees that the ELOR or MAER values provide a more appropriate and accurate estimate of the pre-accident economic value of destroyed equipment than does the depreciated book value. Some railroads cooperated with the Economics Team to develop an analysis comparing the actual repair costs to the FRA reported values for repaired cars and MAER values to FRA reported values for destroyed cars. The study showed that the MAER values were very close, on the average, to the equipment damage numbers reported to FRA. There were some numbers much higher or lower, but the high and low values appear to offset each other, so the Team agreed to accept the value reported to FRA as the best estimate of actual damage.

The Economics Team also could not discern a difference between the reported costs of damage to passenger equipment and the societal cost of the damage. The Team agreed that the best estimator of passenger equipment damage is the reported damage. Passenger equipment is often insured for replacement value, so sometimes damaged equipment is over reported as the cost of replacement equipment. Other times the equipment is reported as the depreciated value of the equipment. There just doesn’t seem to be a pattern which would enable us to use a scaling factor.

d. Track and Right-of-Way Damage

It appears that actual damage reported for track and right-of-way damage is fairly accurate, and reflects societal costs. It may be under reported in some cases, but in other cases it may be over reported as older track and right-of-way may be repaired to better than pre-accident condition. This appears to the Economics Team to balance out over time, and not to be correlated with any reported characteristics. For purposes of this study the Economics Team agrees to use the reported damage to track and wayside.

e. Damage off the Right-of-Way

Some damage may occur to property not on the right-of-way, for example when an overspeed train derails, damaging a building owned by someone other than the railroad. The Economics

Team estimated this damage at $2,000 per PTC preventable accident.[31] Such damage is rare, and cannot easily be attributed to an accident based on any characteristics reported on the accident report form.

f. Hazardous Materials Cleanup

If an accident involves a release of hazardous materials, there may be a cost to clean up the hazardous material and remediate (restore) the environment. Based on data from actual settlements and judgements the Economics Team estimated the cost of cleanup and remediation at $250,000 per hazardous material car releasing. The Team considered using a single cost per incident in which hazardous material was released, but thought that it would be at least as good to base the estimated cost on cars releasing to provide some measure of the severity of the accident. This measure is still far from perfect, as some accidents involving single car releases may have resulted in far more costly clean-ups than some multi-car releases, yet it is the best measure the Team could agree upon.

g. Evacuations

Accidents may lead to evacuations, either because of real or perceived threats to safety from hazardous materials. The Team estimated the societal cost of an evacuation from data on 77 evacuations on which we had data on the duration of an evacuation. These accidents were not necessarily PTC preventable (most weren't) and occurred between 1993 and 1997. We estimated the value of time at $11.70 per hour, plus 30 percent, or $15.21 per hour. We added 30 percent to reflect the involuntary nature of the costs imposed. Unfortunately, one accident, at Weyauwega, Wisconsin, on March 4, 1996, dominated the costs. The Weyauwega evacuation lasted 426 hours, while the next longest lasted 43 hours. The average cost per evacuation was $986 with the Weyauwega evacuation, and $267 without. The Weyauwega evacuation was clearly an outlier, but nevertheless relevant, so the Economics Team compromised on an estimate of $500 per evacuation.

h. Loss of Lading

If there is an accident involving a loaded freight car, there may be a loss to society as a result of loss or damage to lading. In this case railroad payments to shippers are probably very close to the societal cost of lading loss and damage, which based on AAR data is roughly $6,500 per loaded freight car derailed, a figure the Team agreed upon.

i. Wreck Clearing

If locomotives or cars are derailed or destroyed, the railroad would need to remove them from the right of way. This cost includes the cost of mobilizing a crane or rerailing equipment to the

[31] Yard and highway-rail grade crossing accidents are excluded from any definition of PTC preventable accident considered here.

accident site and the cost of employing that equipment. The Team estimated that the cost of mobilizing equipment to an accident site is $2,500 per incident where cars or locomotives are derailed. Once the equipment is there the Team estimated that it would cost $750 to rerail, wreck or transport a freight locomotive which had derailed, and $300 to rerail, wreck or transport a derailed freight car.

Rerailing passenger equipment can be far more costly. The equipment is more expensive, and may be less robust than freight equipment. It needs to be handled with more care. The sites of passenger accidents are more likely to be in urban areas where the right of way is constrained, as in tunnels and sunken routes under streets. Further, the NTSB is far more likely to investigate a passenger train accident, so there may be significant costs while the rerailing/wrecking equipment sits near the accident site, awaiting NTSB's permission to clear the accident. Four commuter railroads' data suggests that the cost per incident of clearing equipment is roughly $75,000 per accident in which passenger cars or locomotives are derailed. The Team agrees with this estimate.

j. Delays

If a train is derailed it will block the track it is on, and may block adjacent tracks. The Team estimated that the average blockage would last two hours, so if the average affected freight train arrived randomly, the average train delay would be one hour, for freight trains, and fifteen minutes for passenger trains, which are likely to be switched around a delay, and would affect the trains that would pass over an average segment of rail in two hours. The Team estimated the average cost per hour of freight train delay at $250 per hour. Thus the estimated cost of a delay would be freight trains per day divided by twelve (the expected number of trains in two hours), times one (the average expected delay) times the cost per hour of a delay ($250).

The Team estimated the cost of passenger train delays, based on 285 passengers per train (a national average), an average duration of blockage of 2 hours (which implies passenger trains per day/12 are affected), an average per train delay of 15 minutes, and an average value of passenger time of $25 per hour. This relatively high per hour value of time is related to the income of train passengers. Many commuter lines have average passenger household incomes in excess of $75,000 per year.

When we multiply 285 passenger per train times $25 per passenger hour times 1/4 hour, we find the cost is $1,781.25 per train. We estimate the number of passenger trains affected at trains per day divided by 12, from 24 hours per day divided by two hours duration of blockage. This works out to $1,781.25 per train times trains per day divided by twelve, or $148.44 times passenger trains per day.

3. System Unit Costs

The Economics team attempted to develop system unit *costs* for any elements of PTC systems likely to be found in multiple architectures, for instance, costs of on-board processors, DGPS receivers, wayside interface units, other wayside costs, additional sensors, transponders, track circuits, and communication systems, and data radio systems, as well as software development costs.

The biggest problem the Economics Team faced in this task was that different architectures would yield dramatically different unit costs for components, although if a system is under legitimate consideration it is unlikely that its total cost would be radically different from the total costs of other systems providing similar levels of function. One system might rely more heavily on central control, another more heavily on distributed intelligence. A key factor is the existing infrastructure and relative concentration of various assets. A railroad which owns a significant communications infrastructure which could be used for PTC might face lower costs for a PTC system which is communications intensive. A railroad which has long expanses of track and relatively few trains would be more sensitive to wayside costs, where a railroad operating many trains in a dense corridor might be more sensitive to locomotive installation costs.

The Economics Team settled on costing a system with a significant central component for levels 2, and 4, a wayside centric system for level 3, and a train centric system for level 1.[32] The Team realizes that other concepts exist, and may be equally viable, but we needed to look at a single concept in order to generate a meaningful cost analysis.

Another issue is effectiveness. The Economics Team effort was designed to go hand-in-hand with the efforts of the Accident Review Team and the CRAM study. The CRAM will look at accidents which the Accident Review Team said were PTC preventable and use a *Poisson* regression to correlate the accidents with other variables. In such a model an accident is either preventable or not (excluding accidents which the Accident Review Team designated as "maybe" preventable). Implicitly the CRAM assumes 100 percent effectiveness. It wouldn't be helpful to use the CRAM to analyze PTC systems with very different effectiveness. For example, one level 2 system might always apply the brakes in a certain conditions, while another might just require the train crew to acknowledge the potential conflict. The system which allows the train crew override might not be as effective, although it might be considerably less expensive, and might be a valid approach to improving safety. Nevertheless, it wouldn't make sense to use the CRAM to compare those two systems. Systems at all levels need to be nearly 100percent effective in order for the CRAM results to make sense, thus the Team added costs to some proposed systems which only address level 1 in order to make them comparable with higher level systems. This does not imply any acceptance or rejection of other concepts by the Team. It reflects the need to make simplifying assumptions to make study of the problem manageable.

There are three main types of costs. There are costs per locomotive or power unit, to cover the installed on-board equipment. There are cost per mile which reflect the costs of installing equipment along the right-of-way. These cost can either be per track-mile, for items which go into the track, such as switch position indicators, or per route-mile, for items like

[32] In a wayside centric system much of the computer processing is done at wayside units, while in a train centric system much of the computer processing is done on-board the locomotive.

communications. The last category are single unit costs. These can cover hardware for a central office or intellectual property like software/hardware development. Each of these types of costs involves an initial expenditure, and maintenance. The Team estimates that maintenance will cost 10 percent of the initial cost per year in service.

a. Locomotive Costs

The Team agreed that costs per locomotive/power unit varied, depending on the level. For level one systems, which could involve only communications to prevent train-to-train collisions, and which might not prevent a train from running through a switch, there would be much less need for communications with the right-of-way, and a much simpler database could be used. The on-board costs, as agreed by the Team, would be about $40,000 per unit. Systems which could perform at levels 2, and 4 would need to get data from the right-of-way and respond to it. Systems at level 3 could use an ITCS-like architecture, and keep more of their computer intelligence on the wayside, reducing the burden on the on-board computer system. That would reduce the per unit on-board cost to about $50,000, compared to about $75,000 for levels 2 and 4. The differences between systems for level 2 and 4 would be in the number of devices communicating with the train, not in the train's response to a communication, therefore the Team estimated that regardless of whether a system was to perform at level 2, or 4, the cost per unit would be the same, $75,000 per locomotive/ power unit.

b. Costs per Mile

Costs per mile depend on the level of PTC adopted and the existing infrastructure. A number of assumptions were made to arrive at the average costs. Major ones are defined here. All mileage distances refer to route miles unless specified otherwise.

Base stations Level 1 requires no base station radios. Levels 2, 3, and 4 will require a base station radio every 20 route miles of covered territory. The average cost of the installation assumes some of the installations will be new, others will be addition of new radio equipment at existing base station facilities.

Yard radios All levels require some means to download databases to locomotives, such as a yard radio assigned to this purpose. Assumed density of these devices is one per 250 route miles.

Switch monitors Levels 1 and 2 use no switch monitoring. Level 2 uses non-vital CTC indications for switch position monitoring in CTC territory as indication of route alignment through an interlocking or control point. Levels 3 and 4 use WIUs at control points to monitor power switch positions, and uses WIUs at all significant hand operated main line switches in CTC, ABS or Dark territory. Power switch locations will require an add-on WIU only. All hand throw switch locations require a stand-alone WIU.

Assumed spacing for monitored switches in CTC territory is 5 miles between power switch locations and 5 miles between significant hand operated switches.

Assumed spacing in ABS and dark territory is 5 miles between monitored switches of whatever type. In this territory, all monitored switches require the switch monitor along with the stand-alone WIU.

Track circuit monitoring Levels 3 and 4 monitor all existing main line track circuits and level 4 adds monitored track circuits in dark territory. Assumed requirement for monitoring existing track circuits are one stand-alone WIU each 5 route miles, in addition to the WIUs installed for switch monitoring, some of which may also monitor track circuits. For dark territory in level 4, new track circuits must be added at the spacing of 2 track miles each, along with additional WIUs to support them at an average spacing of 5 route miles.

Other monitors In level 4 only, additional monitors are assumed to detect bridge displacement and excess wind, and to interface with wayside defect detectors (hot box, dragging equipment, etc).

Bridge monitors are assumed to be installed on significant bridges only, not every span. Bridge monitors require a stand-alone WIU to be used with each bridge monitor. Assumed spacing of the bridge monitors is 20 miles.

Wind monitors will be installed every 250 miles at existing WIU locations, so additional WIUs are not needed for the wind detectors.

Monitoring of defect detectors is needed every 20 miles in level 4 systems. The defect detection requires a stand-alone WIU with each detector, plus the defect detection monitor.

c. PTC System Costs

Object Costs

WIU - Stand-alone	$40,000
WIU - add-on to CP	$20,000
Switch Monitor	$10,000
Bridge Monitors	$40,000
Wind Monitors	$5,000
Defect Detector Monitor	$10,000
Base radios	$45,000
Yard radios	$10,000
DGPS	$0 (We expect the Federal Government to fund DGPS)
Wayside servers - incremental cost	$15,000

PTC System Costs per Mile

Costs per Route Mile

Level	CTC	ABS	Dark
1	$40	$40	$40
2	$2,790	$4,790	$4,790
3	$24,665	$24,665	$16,665
4	$26,970	$26,970	$18,970

[Additional Costs per Track Mile, Level 4, Dark Territory: $7,000**]**

Route Mile Costs

	Miles Spacing	Unit Costs	Per Route Mile
Costs			
Base station radios	20	$45,000	$2,250
Yard Radios	250	$10,000	$40
			=========
			$2,290 Base Comm Levels 2
Bridge Monitors	20	$80,000	$4,000
Wind Monitors	250	$45,000	$180
Defect Detectors in Dark and ABS	20	$50,000	$2,500
Defect Detectors in CTC	20	$10,000	$500

Route Mile Costs (continued)

CTC	$40,000	Cost per WIU
	1	Switches
	5	Miles between un-powered switches

	$8,000	per route mile for un-powered Switch monitors
	$20,000	Control Point Switch WIU
	1	Switches
	5	Miles between Control Point Switch

	$4,000	per route mile for Control Point Monitor
ABS/Dark	$50,000	Switch monitor & WIU
	2	Switches
	10	Miles between meet sidings

	$10,000	per route mile for Switch monitors
Level 3	$15,000	Wayside server increment
	1	server
	8	miles between servers

	$1,875	per route mile
Level 3, 4	$40,000	WIU for track circuits
	2	number of WIUs
	10	spacing between WIU's

	$8,000	Track circuit interface costs per route mile

Track Mile Costs, Additional

$7,000 Track Circuit cost per track mile (level 4, Dark Territory)

Planner and per Locomotive Costs

	Unit Cost	Offset[33]	Net Cost
Level 1	$40,000	$17,000	$23,000
Level 2	$75,000	$17,000	$58,000
Level 3	$50,000	$17,000	$33,000
Level 4	$75,000	$17,000	$58,000

System Development Costs[34]

		Offset by Planner[35]	Adjusted Cost
Level 1	$ 20,000,000	$ 3,000,000	$17,000,000
Level 2	$ 30,000,000	$ 3,000,000	$27,000,000
Level 3	$ 40,000,000	$ 3,000,000	$37,000,000
Level 4	$ 50,000,000	$ 3,000,000	$47,000,000

4. Alternatives to PTC

No economic analysis would be complete without a discussion of alternatives. The accidents which PTC might prevent may also be avoided through other means. While these means may not be as effective in preventing the same pool of accidents, they may be able to address some of the same accidents, and others outside the PTC-preventable pool. Three major areas of potential improvement include addressing human factors in accidents, signalizing dark territory, and enhancing existing signal systems. In addition, advocates of PTC have suggested that PTC may bring various business benefits. There may be other ways of generating similar business benefits.

The FRA is addressing Human Factor issues in several other initiatives:

Fatigue: FRA's goal is to continue to expand Fatigue Countermeasure Programs by providing leadership to the rail industry in researching and developing fatigue countermeasures through FRA's North American Rail Alertness Partnership.

Cab Working Conditions: FRA's goal is to improve the safety and health of locomotive cab occupants. Early in the year, we will endeavor to complete RSAC's consideration of a proposed sanitation standard. During the same period it will be necessary to determine if a

[33]The Offset is the estimated on-board cost per unit of buying a planner which would not be needed were the railroad to purchase PTC and add planning capability.
[34]Includes the following costs: Implementing operating rules; building databases; generating software; developing messages; designing communication infrastructure; and single item costs include software development and, if needed, central office costs. Does not include train management/optimization.
[35]The Offset is the estimated system cost of buying a planner which would not be needed were the railroad to purchase PTC and add planning capability.

current impasse on high-end temperature issues can be resolved so that rulemaking (either under an RSAC consensus or otherwise) can proceed. Later in the year, detailed issues related to cab noise should be resolved, permitting institution of rulemaking on that subject.

Although FRA has established these goals, railroad management and labor organizations have not yet adopted all of them, and reserve their rights to disagree with FRA.

Conventional Signal Systems

Signal systems which don't qualify as PTC still hold considerable promise in reducing accidents. In dark territory signal systems could make existing operations safer, helping train crews avoid many PTC preventable accidents. Some of these accidents might still occur, but signalization is still a valid safety-improvement strategy. In areas where signal systems are in place improving the signals could help avoid PTC preventable accidents. This study does not purport to analyze the benefits or costs of these competing safety improvement strategies, but identifies them for others who may wish to analyze them.

Railroad signal systems are valuable assets to transportation safety. They comprise a critical element of the safe and efficient operation of a railroad. The utilization of signal systems provide for the safety of local residents, railroad employees, equipment and commodities. There are many well-established safety benefits afforded to signal systems. Signal systems presently utilize a fail-safe design and are designed to protect the safety and integrity of railroad operations by providing broken rail and track defect protection, switch and derail alignment protection and route integrity protection, not to mention protection against different types of train and on-track equipment collisions. Furthermore, signal systems are designed to mitigate the dangers caused by human error or acts of vandalism. They also provide additional protection to the sometimes-fragile environments which many segments of track traverse. By providing track integrity protection, additional signal systems could ensure a safer passage for the multitude of hazardous materials that are transported by train throughout the nation. Signal systems also provide an added level of protection for inland waterways, bridges, trusses and culverts that are spread throughout each individual railroad. Enhancing the existing train control system on a specific route might provide some of the same safety benefits as those associated with PTC systems. An analysis has not been done that describes the relative cost/benefit improvements available to such systems.

Locomotive Crashworthiness

Although we would rather prevent accidents than mitigate them, our goal is to enhance the protection of locomotive crew members in serious train accidents. As 1998 ended, tentative agreement had been reached on the basic elements of crashworthiness for freight road locomotives, and work was proceeding on passenger locomotives. During 1999, an NPRM will be completed and comments will be received.

Passenger Equipment Safety Standards

Concurrent with this review of positive train control implementation, which will enhance the crash avoidance capabilities of the national rail system, FRA and the passenger rail industry are also considering ways to strengthen locomotives and passenger cars. The RSAC Locomotive Crashworthiness Working Group, the FRA's Rail Passenger Equipment Rule and the American Public Transit Association's Passenger Rail Equipment Safety Standards effort are all defining standards that will make rail vehicles more crash resistant. Enhancing both crash resistance capabilities with sturdier rail vehicles and crash avoidance capabilities with positive train control are efforts that have significant financial implications for the passenger railroads and the potential to reduce the same group of fatalities and injuries. Because of the overlapping nature of these efforts, FRA needs to ensure that the cost benefits analysis of crashworthiness and crash avoidance are linked and do not double count potential benefits.

5. Other Than Safety Benefits

Because PTC systems have been expensive, there has been thought that consideration should be given to incremental economic benefits which could be achieved through improved railroad operating performance (i.e. not just safety), to help justify the cost. This assumes that there is a synergistic, but dependent relationship between the basic safety system and the operating algorithms needed to improve daily performance. This assumption is true of one particular design philosophy, i.e where safety hardware and software form the foundation of all other systems. However, suppliers in the industry are marketing technologies which they believe would improve operating efficiencies independent of PTC safety systems and at considerably less cost.

At the same time, however, some train control systems designed for safety purposes appear to share many characteristics with systems designed to increase productivity. Both types of system need to know the location of the trains, and may need to inform the train of the actions the system needs the train to take. On-board the locomotive either system needs to have location equipment and may need equipment which takes commands from the system. Each system needs to communicate. Each system must be developed to process logical information regarding the trains' current and future positions.

An important consideration on how much overlap there might be between the technology a railroad might adopt for PTC and the technology a railroad might adopt for planning is the current state of the railroad's infrastructure. Railroads vary widely in their existing infrastructure. Some have more extensive existing communications networks while other railroads have very limited communications networks, leasing the communications capability for business systems. Infrastructure can also vary in terms of miles of multi-track line and traffic density. All of these may affect whether part of the PTC investment might be used for business planning systems.

FRA has informed the committee that there is significant doubt whether a railroad should be permitted to transmit automated pacing information to the train crew without safeguards that would apply to safety-critical data.[36] In FRA's view, it is possible to envision systems where the display might appear to be conveying safety-critical data related to train pacing without assuring the information would be reliable enough for a safety-critical application. If such a system introduced a new hazard then FRA would object to placing it in service. A properly implemented PTC system conveying the same information would have assured that the data would be accurate, so FRA would have no objection to using the data to enhance productivity. Thus, it may be that the only way to implement certain productivity improvements would be to adopt PTC.

PTC systems may create a benefit in terms of increased capacity, especially where the PTC system permits use of flexible blocks. The productivity improvements from flexible bocks are greatest where traffic is greatest, where speed differentials among trains are greatest, and where there are multiple tracks with frequent crossovers. Further, there are some route segments where the railroads can not expand the number of tracks because they cannot obtain additional right-of-way. On these segments the only practical way to increase capacity would be to implement a system which allows a safe flexible block operation.

a. Dependent Systems

As stated earlier, one PTC design philosophy assumes that safety hardware and software form the foundation of the system. The primary benefit is safety, i.e., prevention of train collisions and over speed operations, as well as protection for roadway equipment. Safety is absolutely dependent on the function of this technology. Thus, these systems require varying degrees of vitality, depending on their individual design, which necessitates high reliability in hardware and software. They also require a communications infrastructure (not currently in place) which is capable of handling high data throughput. The communications infrastructure alone can cost as much as $200M per railroad. Together, these attributes require the greatest amount of capital and make the system cost quite high.

Within this philosophy, additional economic benefits can be achieved with incremental capital investment since much of the hardware and software is already in place. The largest benefits include the potential for reduced manpower requirements, elimination of existing wayside signals, increased infrastructure throughput (capacity), equipment utilization, and fuel savings. Of these benefits, only the elimination of wayside signals and the potential for reduced manpower (which is outside of the scope of this report) are truly dependent on the vitality required for the PTC safety systems. (In fact, additional vitality may be required for these concepts.) The remainder can be achieved independent of the PTC safety systems.

[36]This issue arose for the first time in the spring of 1999. FRA has not formulated a formal position on this matter. Indeed, the actual conditions under which train pacing information might be proposed to be sent are not currently known.

b. Independent Systems

Suppliers are offering systems which may offer much of the benefit previously thought to be dependent on the advent of Positive Train Control, independent of the PTC systems, and at considerably less cost. Most of the benefit comes from improvements in infrastructure throughput, equipment utilization, and fuel savings. Each of these is dependent on the presence of a network system planner, a location determination system placed on-board most locomotives, and sufficient communications infrastructure to communicate position and pacing information.

c. Infrastructure Throughput

A railroad computer based network planner can prioritize the movement of trains such that it may improve overall throughput. The use of a network planner seems to be a prudent business practice, independent of the advent of PTC. Planning is accomplished by organizing the travel sequence for all trains in an entire marketing corridor or network. The plan is based on required schedule, the consist size, yard holding capacity and commodity. Some planners are capable of addressing anomalies in the plan such as locomotive failure, slow order or derailment. They make repairs to the plan for all trains affected by the event. The overall result of these capabilities is improved equipment velocity and throughput. In a March 1991 technical evaluation, SRI International reported that if a planning system were installed as an integral part of the ARES type system, 70 percent of the total benefits of the ARES (PTC) functions could be achieved through the planning system - the “largest contributor to the net present value...”.

The success of this theory is dependent on two factors: that the new planner is better than that which is used currently and that there is sufficient business to warrant or enable an improvement. Independent studies by individual railroads have shown the relationship between business level and planner benefit. The relationship is marketing corridor dependent. Without sufficient business or congestion, there is little need for these systems.

Benefits may also be achieved when the need for additional track is delayed or eliminated because the planner has made the existing infrastructure more productive. In either case, there is a financial offset to the investment required.

d. Equipment Utilization

With improved planning and increased velocity, the number of units of equipment needed to service the current traffic can decrease. Improved planning has the potential to reduce the overall locomotive fleet size required to serve the network. Improved car velocity can increase the number or turns of cars achieved annually. While this is somewhat dependent on the release of the equipment by customers following delivery, the potential for savings is certainly present. The improvement is business level dependent, i.e. higher levels of business are required for justification.

e. Fuel Savings

Because of the potential for pacing of trains in the planning scenario, locomotive fuel consumption should improve. The potential savings amounts to a few percent of the railroads fuel bill in the marketing corridor. Again, there must be sufficient business level in the corridor to realize the improvement.

f. Balancing Cost and Benefit

Railroads the size of the four major systems in the United States could spend on the order of $500M to $600M each on full PTC systems that provide both safety and productivity improvements on core routes. The investment required for productivity improvements alone is roughly 20 to 25 percent of the capital required for full PTC, implementing productivity benefits in a fixed block system, while 70 percent or more of the benefit might be achieved without investing in the safety elements of the system. In either case, the return on the investment will be dependent on the business level in the marketing corridor.

Locomotives	16,410
Percent Equipped	100%
Roadway Machines	50,000
Beacon: Level 1	$5,000
Percent Equipped	50%

	CTC	ABS	DTC
Route miles	43,560	16,373	40,663
Track Miles	63,259	22,978	55,907

Class 1 Roads: 5

TOTAL INITIAL ACQUISITION COST

	Level 1	Level 2	Level 3	Level 4
CTC	$1,742,400	$121,532,400	$1,074,407,400	$1,174,813,200
ABS	$654,920	$ 78,426.670	$403,840,045	$556,190.810
DTC	$1,626,520	$194,775,770	$677,648,895	$1,162,726,110
Locomotives	$377,430,000	$951,780,000	$541,530,000	$951,780,000
Development Costs	$85,000,000	$135,000,000	$185,000,000	$235,000,000
Roadway Machines	$125,000,000	$ -	$ -	$ -
Total	$591,453,840	$1,481,514,840	$2,882,426,340	$3,965,899,120

PTC BENEFIT/COST SUMMARY

Benefits and Costs of Implementing PTC on the Five Largest Railroads, on all lines

[Twenty-Year Discounted Benefits and Costs]

		Total Benefit		Benefit/Cost Ratio	
PTC Level	System Cost	Including m's	Excluding m's	Including m's	Excluding m's
1	$1,162,748,683	$485,264,906	$465,225,946	0.42	0.40
2	$2,912,534,017	$501,828,683	$496,228,031	0.17	0.17
3	$5,666,608,622	$539,413,580	$533,686,545	0.10	0.09
4	$7,796,625,307	$843,965,546	$555,335,201	0.11	0.07

Note: "m's" are accidents coded as maybe preventable by the Accident Review Team

The Economics Team prepared a total cost sheet to demonstrate what the cost of implementing PTC on all of the lines and all of the locomotives of the five largest Class I railroads (CSXT, NS, BNSF, UP, and Conrail). This is only a demonstration exercise to illustrate an upper bound to costs. No one believes this is a practical implementation. Many of the low density lines on those railroads would be poor candidates for an upgrade to PTC. When railroads implement PTC, the most likely migration path would be to implement PTC first on those corridors where PTC returns the highest net benefit. These probably will be high density lines with passenger or hazardous material traffic. Even if a railroad were to adopt PTC "completely", it might not equip all of its locomotives or power units (although some railroads have said they would equip all of their locomotives even if they only put PTC on a single corridor), and it might not equip lines where traffic density is so low as to preclude collisions. Nevertheless, the total cost of implementing PTC on the five largest Class I railroads provides a useful measure of the scale of costs.

Through the Volpe National Transportation Systems Center, FRA had commissioned a study of other-than-safety benefits of business systems associated with PTC. The study analyzed the benefits of business systems associated with PTC and concluded that these benefits fell into five categories:

1) reduced yard and transit time from improved work order reporting;
2) reduced maintenance hours and en-route failures from locomotive diagnostics;
3) fuel savings;
4) reduced costs from improved equipment utilization and
5) higher revenue from improved customer service.

FRA further believes that systems associated with PTC can contribute additional benefits by providing current information which can help with crew scheduling and profit maximization. The systems may also help identify less efficient operations within a railroad, enabling the railroad to improve the effectiveness of its middle management, and may help the railroad better target other infrastructure improvements.

A railroad might achieve these benefits by adopting a network system planner, a location determination system and sufficient communications infrastructure to communicate position and pacing information. These can be purchased independent of a PTC system, but once you have decided to pay for these, it may be less expensive to add a PTC system because it relies on the same information. A PTC system would need location determining equipment, and equipment to communicate position and might need equipment to receive pacing information. A PTC system also needs some processing capacity to ensure train separation. This processing capacity is similar to the capabilities needed to support a traffic planner.

The Economics Team estimates that the cost of a PTC system may be offset by about $17,000 per locomotive/power unit, and about $3,000,000 for development. Onboard equipment cost is partially offset because the PTC system would have to include positioning equipment and a data screen sufficient to execute the requirements of a planning system, and the communication system required for PTC would obviate the need to purchase commercial communication for the planner. In addition, the software team developing the planner or PTC would benefit from their knowledge of the railroad's operation were they to develop a PTC system or planner subsequently, would be able to reuse code dealing with processing positioning messages, and would be able to make dual use of the track database.

The Economics Team noted that if there were great benefits to be gained be adopting a planner, then a planner would likely be implemented without regard to PTC implementation. Thus the absolute magnitude of benefits from the planner is not relevant, as long as the benefits of a planner far exceed its costs. What is relevant is the synergistic relationship between the planner's development and development of a PTC system.

g. Integrating the Benefit Analysis with the Cost Analysis

The safety benefits of a PTC system on a Corridor can now be estimated using the Corridor Risk Assessment Model. Once that is done, the costs of installing PTC on those corridors can be estimated using the unit costs developed here. These unit costs cannot be applied until we estimate the number of locomotives which must be equipped in a corridor.

VI. Development and Deployment of PTC Systems

There are a number of critical issues facing the railroad industry in the development and deployment of PTC systems. Some of these issues relate to the technical, schedule, and cost risks associated with the development of this new technology; some relate to challenges associated with deployment and operation in a large, diverse industry; and others relate to national-level technology infrastructure necessary for PTC to be cost-effective and viable. These issues have to be viewed from three different perspectives – national, the railroad industry, and individual railroad levels.

The key PTC development and deployment issues at the national level are radio spectrum availability, and implementation of a differential GPS network that covers all areas where railroads operate. PTC will use radio datalinks between trains and wayside, as well as other applications, as part of the basic system architecture. Successful deployment of PTC will require that sufficient radio frequency spectrum (capacity) is available to the railroad industry, on a dedicated basis, to support the safety-critical communications that provides the backbone of a PTC system. Without clear radio channels, PTC cannot be deployed even if the technology is proven to satisfy the necessary functional and safety requirements.

At the railroad industry level, the Illinois PTC pilot program, along with other pilot and test bed PTC installations, will lead to refinement of the PTC requirements and evaluation of candidate system architectures and technologies. The industry PTC program will also produce standards that define the detailed requirements for PTC functionality and interoperability. The Illinois High-Speed Rail corridor will provide a test bed for evaluating PTC technology for application to freight and passenger operations.

At the individual railroad level, railroads will use the PTC standards as the basis for specifications and bid packages to procure PTC systems. However, PTC cannot be installed overnight, and will not be installed on all operating territories. The fact that locomotives traverse different territories within a railroad, as well as different railroads, presents special challenges in supporting railroad operations, particularly during the period when PTC is initially being installed. In addition, the industry is preparing to undergo a major change in its radio infrastructure, presenting an additional system migration challenge. These challenges will require development of mechanisms to ensure interoperability of systems as locomotives move around the country, and to facilitate safe and efficient operations in situations where an unequipped locomotive (or a locomotive with a failed PTC system) is operating in PTC-equipped territory. Practical and safe deployment of PTC will require that rules, regulations, and systems accommodate operations in a mixed mode of PTC and other means of train control.

The subsections that follow address these PTC development and deployment issues in more detail.

A. Railroad Logistical Considerations

1. Technology Challenges

There are a number of challenges associated with the implementation of PTC technology. These challenges include the underlying technologies of PTC systems, and deployment of PTC in the railroad environment. The technology challenges include:

1. Radio Data Link – The industry must develop a radio data link with the capacity and characteristics suitable to real-time, safety-critical train control.
2. Location Determination System – A location system must be proven to provide the train location accuracy, integrity, and availability to meet PTC requirements.
3. Displays – PTC on-board information display requirements must be defined to achieve interoperability, and technology must be selected that will meet the rigorous railroad operating requirements in terms of physical ruggedness and suitability to use by typical train operators.
4. System Integration – Integrating the complex hardware and software elements of PTC systems represents a system integration challenge. Functions and software are distributed between mobile and fixed platforms, and the definition of messages and control logic must be precise to ensure both safety and interoperability. Experience across many industries in recent years provides testimony to the difficulties in fielding reliable systems that include geographically-dispersed systems with complex software interactions.

a. PTC Design for Specific Risks

PTC systems being tested by different railroads have been designed to address the risks associated with specific corridors, traffic patterns, and operating environment. These systems all perform the core PTC safety functions, while their detailed designs reflect the operating requirements and safety risks of the corridors on which they are implemented. The flexibility of PTC to address these corridor and railroad specific needs represents a significant advantage of the technology. There is no universal, "one size fits all" implementation of PTC; systems must be implemented in a way that addresses the risks of specific corridors in the most cost-effective manner.

b. Core Infrastructure Requirements

Deployment of PTC systems will require either upgrading or new installation of a number of communications and information systems on individual railroads that complement the PTC hardware and software that will be provided by PTC systems suppliers. These infrastructure elements are discussed in another section of this report.

c. System Testing and Verification and Validation

PTC systems represent a jump in technology for the railroad industry and its suppliers. They will require extensive testing to ensure that they meet all applicable safety design criteria as well as perform the specified functions. PTC systems will contain large amounts of new software that is distributed among mobile and fixed processors, with landline and radio communications linking them. Extensive software testing, possibly including the use of simulators as well as factory and field testing, will be required to ensure that the software not only provides the basic functionality, but reacts safely when unexpected or unplanned events occur. PTC systems must be demonstrated to exhibit design characteristics that are suitable to the railroad environment in terms of reliability, maintainability, ergonomics, configuration management, and the physical requirements of shock, vibration, temperature extremes, and humidity. Verification and Validation (V&V) procedures and standards will be developed for PTC systems as part of the AAR/FRA/IDOT PTC program. Test procedures will also be developed for the system to be deployed on the IDOT corridor.

d. FRA System Approval

Many PTC system implementations represent a significant change in technology from current traffic control systems. FRA regulations that have been applied to the design, operation, and maintenance of existing systems are not all suitable for application to processor-based systems. The PTC RSAC Standards Task Force is developing new rules, standards, and instructions for consideration that are designed to apply to processor-based systems. There will be a number of challenges to all parties involved in the deployment of PTC systems – railroads, suppliers, labor, and the FRA – to apply these new regulations appropriately. Inevitably, changes in both PTC system designs and the new regulations will be required to adapt to the new technology.

e. Migration From Existing Systems

Implementation of PTC requires deployment of new systems without disruptions to rail traffic, without causing safety problems during deployment, and while making use of as much existing infrastructure as possible. The railroad supply industry will develop PTC systems that take advantage of existing product developments and existing railroad infrastructure. Just as the railroads cannot afford to implement PTC at a rate that cannot be cost justified, the suppliers cannot write off investment in current product lines overnight to develop PTC systems. Migration from current systems and products to PTC systems is essential to making PTC deployment cost-effective and realistically achievable. This means that migration strategies to implement PTC capability in phases must be developed. Experience in deploying complex new systems like the air traffic control system has shown that “flash cutovers” do not work, and can cause more safety problems than they are intended to address. The starting point for migration to PTC differs by railroad and territories or corridors, as well as by supplier. This translates to variations in PTC configurations for some time, complicating achievement of many of the projected benefits of PTC and the return on investment required to justify PTC costs. Development of carefully planned migration plans from current systems and operations to PTC will have to be accomplished in concert with the development and test of PTC technology for achieving the projected PTC benefits.

f. Rate of Deployment

Once PTC technology has been developed and tested, and the regulatory structure has been modified to facilitate system approval, the rate of deployment of PTC systems will be determined by cost justification, availability of capital and operating funds, migration from existing traffic control systems and associated infrastructure, and availability of proven products from suppliers. Deployment of new systems, particularly those involving new technology, always takes time. Problems in system design and performance are to be expected, requiring parallel operation with existing systems for some period. PTC equipment has to be installed on geographically-dispersed wayside locations, and on locomotives that are in short supply and utilized to their capacity. The simple physical limitations of installing and testing the hardware and software will limit the rate of deployment of PTC systems, just as it does for military, air traffic control, and other high-technology systems.

g. Unequipped Trains

A complicating factor in railroad operations is that locomotives are typically not dedicated to a specific corridor or route. Locomotives are assigned as needed to address current operating requirements. This means that a locomotive equipped with PTC equipment will be in non-equipped territory part of the time, and that it will be necessary to assign non-equipped locomotives to operate through PTC territory. This situation will be most prevalent during the initial deployment stages of PTC systems. Rules will be required to support the operation of unequipped trains through PTC territory, and the PTC system design must be able to identify the presence of unequipped trains (or other unequipped vehicles) on the track and ensure safe operation.

h. Interoperability

Achieving interoperability between different PTC system implementations by different suppliers will require comprehensive definition of the interaction between diverse system elements. Standards will be required to define system functions, the logical interaction of these functions, the communications and messages between different subsystems (such as train to wayside), and the integrity checks necessary to ensure that errors are not made due to exchange of bad data, timing anomalies, data context ambiguities, accepting commands from the wrong source, and other logical inconsistencies. Defining PTC system standards that provide the framework for achieving interoperability requirements without restricting system implementation and technology innovation represents a major challenge. There is no “one size fits all” solution to PTC, yet interoperability of systems developed for different traffic corridors is a critical element to ensuring that systems are cost-effective as well as safe.

i. Training

Deployment of PTC systems will require the development and execution of new operating and maintenance training programs. The installation, testing, operation, and maintenance of PTC will encompass new technology, new rules and regulations, new procedures, and new operating practices. Successful implementation of these new training requirements will require cooperation between railroads, labor, and the FRA, and will impose new challenges on suppliers of traffic control systems.

j. System Configuration Management

Management of the configuration of processor and software-based systems represents an area of expertise, procedures, and tools that the railroads and their suppliers have only recently begun to gain experience. Standard practices for configuration management of processor-based system is in an evolutionary stage. Making changes to current-generation software and processor systems used in the railroad industry has proven to be very expensive. Railroad personnel are often not able to make software changes due to the design of the software, availability of expertise, or commercial practices of the suppliers. In order for PTC systems to be cost-effective to maintain, to remain safe in operation over time, and to facilitate system expansion or enhancements, the industry must develop system configuration standards and practices that are appropriate to PTC or other safety-critical systems. The railroads are not alone in addressing this challenge. Activities are underway in other industries nationally and internationally to define configuration management standards for safety-critical software.

B. NDGPS – An Enabling Technology

1. Introduction and Summary

The Air Force designed the Global Positioning System (GPS) as a dual use system to meet the needs of both military and civil sectors. As a result, the GPS signal specification defines two services. The first is the Precise Positioning Service (PPS), which is for the military and select government users and has a horizontal accuracy of 22 meters. The second is the Standard Positioning Service (SPS), which is available to the general public and has a horizontal accuracy of 100 meters.

The Differential Global Positioning System (DGPS) is now available to marine users all along the entire United States coastline and throughout our principal inland waters. Under this system, differential correction signals are transmitted from fixed ground stations, at low frequency, for processing with raw GPS signals from a constellation of satellites to achieve accuracy in practice of 1 to 3 meters. Intelligence at the differential beacon site determines the variance (vector) between the beacon's true location and that determined from SPS data, and uses the information to broadcast correction data which is used by GPS receivers to enhance the accuracy of the location solution.

With an incremental expenditure of less than $35 million, sufficient additional transmitters (67) can be placed to provide redundant coverage of the 48 contiguous states and Alaska. This highly accurate position, navigation, location, and timing system will then be used by both rail and highway users, among others. Public, nationwide deployment of DGPS (operated, maintained, and integrity monitored by the Federal Government, and free of user fees) will be necessary if this system is to be standardized nationwide for all users. Private differential services do not offer high reliability, consistent protocols, and full land area coverage – attributes that are essential to interstate rail movements employing interoperable train control systems.

With leadership from the FRA, the Office of the Secretary of Transportation, and the United States Coast Guard, a Nationwide DGPS network will be deployed. Constructed largely from infrastructure being retired from national defense uses, that network will be an enabling technology for PTC and many other civilian uses.

2. NDGPS Deployment

As noted above, the Coast Guard is already deploying DGPS for harbor and inland waterway navigation. The 61 radiobeacon transmitters of the Maritime DGPS Service were in place and declared to have Full Operational Capability on March 15, 1999 at a cost of $17.2 million, plus $5.0 million in maintenance annually. Initial operating capability was declared for the first eight sites of the Nationwide Differential Global Positioning System (NDGPS).

Currently, the Coast Guard's Maritime DGPS network covers the coastline of the United States and navigable waterways of the Mississippi River. The system was designed to be fully compliant with the RTCM SC-104 and ITU-R M.823 domestic and international standards, respectively. In fact, 35 nations currently operate systems that are modeled after the United States Coast Guard DGPS, and are compatible with the RTCM and ITU standards, thus providing the basis for a seamless worldwide navigation system.

In January 1997, the Department of Transportation formed an interagency NDGPS Executive Steering Group and NDGPS Policy and Implementation Team to lead the implementation of the nationwide system. The NDGPS Policy and Implementation Team documented the requirements of many Federal and state agencies, evaluated alternative methods of providing differential corrections, documented benefits, and developed a cost-benefit analysis in accordance with OMB circular A-94. This work is documented in the team's *Nationwide DGPS Report*. Many public safety applications are identified in the report, including saving lives on the railroads and highways.

In an unprecedented level of cooperation among Federal and state agencies and industry, the United States is now developing a Nationwide Differential Global Positioning System (NDGPS). The development of the NDGPS will leverage the Department of Defense's investment in the Global Positioning System and the Coast Guard's investment in the maritime Differential Global Positioning System to provide a cost-effective navigation system. In fact, NDGPS will soon blanket the Nation with the most accurate and most reliable navigation service the United States has ever had.

Expansion of the proven Coast Guard design will only cost $35 million to implement on a national basis. In fact, the net present value of the 15-year-system life costs are only $68.6 million, while the life cycle benefits are estimated in the range of $10.4 billion, yielding an impressive benefit-to-cost ratio of 152:1. The low cost associated with this project is to a large extent the result of an opportunity for defense conversion. Conversion of the Ground Wave Emergency Network (GWEN) sites that the Air Force is decommissioning into DGPS reference stations will save the Department of Defense about $6 million in GWEN decommissioning costs, and save the Department of Transportation about $10 million in NDGPS implementation costs, while providing improved facilities that are hardened against weather and other hazards. It is a "win-win" situation for both the American taxpayer and the governments at the Federal, state, and local levels. The passage of Public Law 105-66, Section 346 (October 27, 1997) provided both the authority and the funding to immediately begin installations.

3. Proof of Concept for GWEN Conversion

Since DOT's plan is to reuse the Air Force's GWEN sites as they are decommissioned, FRA asked the Air Force if a site could be removed from the network to convert it into an DGPS site as a proof of concept. The GWEN site in Appleton, Washington, was converted and activated in May 1997. This first DGPS site has been transmitting flawlessly since then. Moreover, the efficiency of the 300 foot, reused GWEN antenna far exceeded initial expectations.

While a typical Coast Guard DGPS antenna is between 13 and 17 percent efficient, it was anticipated that the larger GWEN antenna would have an efficiency of about 35 percent. But the near perfect match between the antenna and the DGPS frequency resulted in an exceptional 51 percent efficiency. This means that instead of radiating 130 to 170 watts, which is the power delivered by a typical Coast Guard antenna, the converted GWEN antenna radiates 510 watts. The range of the Appleton site is 200 to 250 miles, depending on the terrain and ground conductivity.

The Appleton site has also been used as a proof of concept for the use of DGPS in the Positive Train Separation system.

4. Background and Technical Detail

PTC applications demand better accuracy, integrity, and availability than either the SPS or even the PPS services provide. The first augmentation system that could address these shortfalls is the Coast Guard's Differential Global Positioning System. The Coast Guard needed a radio-navigation system, which would provide better than 10 meters accuracy along navigable waterways of the United States to improve the safety of maritime traffic. The Coast Guard's DGPS uses a system of reference stations to provide range corrections and integrity checks to users up to 400 kilometers from the reference station. The range of the signal is a function of the transmitted power of the reference station, the ground conductivity, and the skywave propagation of the signal.

The reference station continually monitors all of the GPS satellites that are in view. Since the reference station is surveyed, its precise location is known. Using this known position, the reference station calculates a correction for each satellite that is in view. The users receive the

GPS signals from the satellites and the DGPS corrections from the reference station. Applying the corrections to the satellite pseudoranges gives the DGPS user an accuracy that is typically between 1 to 3 meters, depending on the distance the user is from the reference station. The accuracy near the reference station is approximately one-half meter, but the accuracy degrades by about 1 meter for every 150 kilometers in distance that the user is from the reference station.

In addition to accuracy, integrity is essential to the navigation systems. Integrity refers to knowing if the GPS signal can be trusted for a location solution. Unfortunately, it can take 2 to 4 hours for a GPS satellite which is operating outside the acceptable parameters to pass over a control site where it can be flagged as being out of tolerance. DGPS, on the other hand, continuously monitors the satellites and, if a satellite is so far out of tolerance that it cannot be corrected, the user is notified within 2.5 to 5 seconds. This "time to alarm" integrity is very important in safety-critical applications such as PTC.

In addition to the accuracy of 1 to 3 meters and the integrity time to alarm of 2.5 to 5 seconds, the DGPS will provide dual coverage nationwide. That means, anywhere in the country, corrections will be available from at least two reference stations. Thus, if an unusual occurrence eliminates the signal from one reference station, such as a lightning strike at one of the reference stations, or radio interference that jams one reference station, the other reference station will ensure continuous service. The percent of time that a service is available is referred to as operational availability. Since a single reference station is designed to provide an operational availability of 99.7 percent, dual coverage will provide an availability of 99.999 percent.

5. Role of DGPS in Train Control

Deployment of a Nationwide Differential Global Positioning System can significantly aid the development of positive train control systems by providing an affordable and competent location determination system that is available to surface and marine transportation users throughout the contiguous United States and Alaska.

PTC systems will require a location determination system that is more accurate than non-differential GPS. The NDGPS network will significantly enhance the utility of GPS for PTC applications. However, PTC pilot programs have shown that even differential GPS does not provide sufficient accuracy, with the required level of assurance, to determine which track a train is on. To address this issue, other sources of information about train location, assigned train route, switch settings, and train movement can be used to resolve train location ambiguities. However, differential GPS is a necessary starting point for these approaches.

One of the principal issues related to PTC is affordability. Differential GPS capability must be available throughout the national rail system and be compatible with interoperable PTC systems if affordability is to be achieved.

6. Completing DGPS

The Department of Transportation and Related Agencies Appropriation Act, FY 1998, Public Law 105-66, Section 346 outlines the requirements and establishes the authority for DGPS. The law also provides $2.4 million, in fiscal year 1998, to begin the installation of the system.

The FY 1999 Act continues funding, with an additional $7.5 million available for deployment of the system.

The DGPS system will be installed using commercial products and services and will be maintained through commercial service contracts. Thus, the DGPS program maximizes the use of commercial products and services.

The NDGPS will reuse GWEN sites which the Air Force no longer needs. The Air Force has 53 operational sites and 6 spare systems. The program will reuse the 300 foot antennas, two equipment shelters and a 25kW generator at each site. Since DGPS coverage model predictions indicate that 66 sites will be required, it will be necessary to purchase some additional antennas, equipment shelters, and generators or battery backup units.

Not all of the GWEN sites are where they are needed. Thus, some of the sites will be moved to new locations. The plan calls for 33 GWEN sites in their current locations, 26 moved GWEN sites, and 7 new sites. The sites will be installed in two phases. The first phase will provide single coverage to the entire country. The second phase will provide dual coverage. Based on current budget constraints, the program will take four to five years to complete, but acceleration of the program is feasible if user needs require it and funding is made available.

C. Radio Frequency Spectrum Requirements

The freight, and passenger railroads in North American have licenses from the Federal Communications Commission (FCC) (and its counterpart in Canada, the Department of Communications) in three major bands, 160 MHz (VHF), 450 MHz (UHF) and 900 MHz (UHF). The VHF band is used primarily for voice communications, including all dispatch communications with trains. The 450 band is used for EOTs and distributed power. The 900 Mhz band was secured for ATCS and is used primarily for code line and work order. The code line application provides for control and monitoring of switches and signals in traffic control territory.

There is uncertainty over whether or not the available spectrum is sufficient for nationwide implementation of PTC. At 900 Mhz the number of channels (6) is likely to make the use of this spectrum in major cities very difficult, without additional channels. The 450 bandwidth is already used for EOTs and distributed power and has the same number of channels as the 900 band. The majority of the available bandwidth is at 160 MHz, which is subject to regulatory action by the FCC, and is currently used for all railroad private analog voice communications, making its use in a digital nationwide PTC network problematical. Generally, analog voice systems use simplex operations (transmit and receive on the same channel) and digital data networks, like those proposed for PTC work best on duplex or half-duplex systems (transmit and receive on different channels).

Currently freight railroads are evaluating different means of increasing the channel throughput for the 900 Mhz channels, and evaluating new technology for voice plus data radios at 160 MHz.

The FCC, in rulemaking dated April 17, 1997, made several changes to the private land mobile radio (PLMR) spectrum below 800 MHz. These changes were made to “encourage more efficient use of the PLMR spectrum.” The principal changes were to consolidate PLMR service groups and to require that new radios by a certain date operate on narrower band channels.

The railroads retained the right to coordinate the radio spectrum it currently uses, but are affected by the narrowbanding. This FCC action offers both opportunity and difficulty. Opportunity in that refarming will allow the railroads to have more channels, can use trunked networks, and can restructure those channels to meet current and future communications demand. Difficulty in that refarming needs to be done correctly to avoid technical errors and costly solutions.

Early on in the refarming process, the communications officers of the major freight railroads realized that the railroads needed to be prepared to cope with refarming through direct involvement in the rule-making process, and in the selection of technology for new radios required by the FCC actions. The involvement in the rule-making process was very successful in that the railroad coordination role was retained, trunking was allowed, and a less prescriptive rechannelization approach allowed. Through the Wireless Communications Task Force (WCTF) the railroads selected the APCO 25 protocol for the new 160 MHz radios and developed a model rechannelization plan.

The rechannelization plan calls for 10 eight-channel duplex, trunking blocks wrapped around a 52.5 KHz band, which could be used for simplex communications. The eight channels blocks would be co-located at base stations, and both the transmit and receive channel would be located at repeater sites, and be transmitting and receiving at the same time. The rechannelization plan will support current analog operations as well as the proposed new digital operations using APCO Project 25 [a more detailed discussion of APCO 25 is on the following page], implying a migration path from analog to digital equipment, where both systems are likely to be operating in close proximity. Given the close spacing of the blocks, and channels within a block, how well the system will perform remains to be seen.

As a result of the FCC’s radio spectrum realignment initiative, land mobile radio users must incorporate spectrally efficient, narrowband technology into their land mobile networks or risk being relegated to a secondary, non-interfering, user status in their currently authorized primary frequency pools. The railroad industry has responded to this initiative with the WCTF, an ad-hoc industry committee dedicated to solving radio communications issues unique to the railroad industry. WCTF members serve in a voluntary and cooperative role and represent the telecommunications divisions of their respective railroads in North America. WCTF is currently considering how to best migrate the railroad industry's existing 160-MHz analog land mobile radio equipment to more modern, spectrally-efficient systems and is developing a strategy to accomplish this migration.

The FRA wishes to ensure that adopting WCTF's recommendations will not detract from the current level of railroad operations efficiency or adversely affect public safety. The Institute for Telecommunication Sciences Boulder (ITS Boulder), the research and engineering arm of the United States Department of Commerce’s National Telecommunications and Information Administration, has performed work related to these issues, and the applicable results are reported here.

The first benefit of the radio spectrum realignment initiative was the doubling of the number of radio channels in the VHF band, from 91 to 181. This was accomplished by halving the allowable transmission bandwidth of radios.

In regions with a high volume of radio communications traffic, an immediate doubling of available channels to serve these areas was not realized because the existing radio equipment, with its wider bandwidth, would "splatter" signals into immediately adjacent narrowband channels. This is somewhat analogous to the interference one would experience when tuning a television set to channel 5 and observing the interference effect that a local television station transmitting on channel 4 has on channel 5 reception. Some degree of geographical separation is required between a base station operating on one of the original railroad channels and a base station operating on one of the newly created adjacent railroad channels, but the amount of geographical separation is much less than that required between base stations operating on the same channel, so there is an increase (albeit somewhat less than double) in the number of radio channels available to serve a geographic region.

To further improve railroad radio communications, the railroads have agreed go beyond the currently practiced "dedicated channel" approach whereby, for example, yard operations have their own specific radio channel. Utilizing a concept known as trunking, many more user groups can be served by sharing a finite number of radio channels, just like a finite number of telephone trunk lines between telephone central office switches are shared by large numbers of individual telephone customers.

Incorporating trunking strategies requires locating multiple base station radios at a single site. This requires that the base stations transmit on one frequency and receive on a different frequency (duplex operation). The reason for using duplex operation is to protect a receiver from being overloaded by a signal from a transmitter. If all the base station transmitter frequencies are grouped together, and all of the base station receiver frequencies are grouped together, then special filters known as duplexers can be used to protect the receivers from being overloaded by strong signals from one or more of the co-located transmitters.

The Association of Public Safety Communications Officials (APCO) developed a series of specifications for new radio equipment and systems. The series of standards are known as APCO Project 25, or simply P25. This new equipment is narrowband, uses digital modulation, and will support trunking, encryption, private call, group call, voice plus data, talk group precedence, and other important functions and features. P25 radios are backward-compatible with older-generation analog FM equipment, permitting a phased migration to infuse the new equipment into service.

Public safety users (police, fire, etc.) are adopting equipment conforming to the P25 standards. Adopting a single equipment standard across multiple user communities enhances interoperability between different agencies. Adoption of the P25 standard by the railroads could enhance the ability for railroads and public safety entities to interoperate with one another in safety-related situations.

ITS Boulder performed a series of measurements to relate the delivered audio quality of speech signals transmitted through P25-compliant radios to radio sensitivity, adjacent-channel rejection and co-channel rejection parameters. The measurements were performed with the radios operated in both P25-digital and conventional analog FM modes. From this data, a representative case study illustrating the improvement in radio coverage afforded by the P25 platform was performed.

The hypothetical site was assumed to be the Brownson, Nebraska microwave site. For a 5-watt hand-held portable analog FM radio and a 5-watt hand-held portable digital P25 radio the P25 digital mode afforded an improvement in coverage over analog FM systems of 8100 square kilometers vs. 6290 square kilometers, for a given level of speech intelligibility. Or, in other words, an increase in coverage area of 28 percent. Existing analog base stations could be upgraded to incorporate P25 technology, without requiring that additional base station sites be constructed.

In summary, the FCC's spectrum realignment initiative is requiring that land mobile radio users incorporate spectrum-efficient techniques or risk the loss of their primary user status within their current land mobile radio band. The railroads are addressing this issue, and recommend that the industry move to a P25 platform and incorporate trunking technologies. Doing so will increase communications capacity to support major new emerging requirements, such as PTC/PTS. Many issues related to these new requirements are not yet well defined, and the railroad industry is studying how to best meet the anticipated demand.

D. Commercial Viability of PTC

Several issues need to be considered both during and after the deployment of a PTC system. Interoperability, where the locomotives of one railroad will operate onto the property of another railroad with full PTC capabilities is one. Another issue is intraoperability, where unequipped trains may operate among equipped trains.

1. Interoperability

As defined by the RSAC Implementation Working Group, interoperability is "the capability of PTC-equipped trains, locomotives, or other on-track vehicles to operate safely on other railroads, while maintaining at least the minimum (or core) PTC functionalities. The intent of PTC interoperability includes the elimination of interline delay and standardization of operator interfaces."

At the moment there are several systems being supported by FRA to achieve positive train control/separation. These systems use radio frequencies to move positioning information and movement authorities between locomotives or maintenance-of-way forces and control centers. These systems will be interoperable if the information messages that they move have the same content, follow the same protocol, and move on the same frequencies. In this context, interoperability means that a locomotive can move among different systems, communicating with and being subject to control by, the host PTC system. Ideally, the handoff from one system to another should be transparent to the operator and automatic, so that no interruption in enforcement capability will occur. Historically, Amtrak has accomplished interoperability by equipping locomotives with hardware responsive to each of the systems, with a switch operated by the engineer and on-board controls responsive to all ACS/ATS/ATC systems over which Amtrak operates and providing a switch for the engineer to use to turn on the proper system for the track over which the train is operating.

Practically, interoperability is a major concern. Until 1993, the freight railroads' commitment to ATCS planning offered the greatest possible assurance that locomotives equipped with the new train control system would be interoperable.

Theoretically, any number of disparate systems can be made interoperable, but practically it is very difficult. Interoperability is affected by the following factors: cost, and penalty in terms of complexity and compromised reliability. In the Intelligent Transportation Systems program of the DOT, interoperability is being achieved through the development of a common architecture, rather than through the development of "translators" between systems with different architectures.

Some of the PTC systems under development should likewise be compatible and will require similar treatment for interoperability if they continue to mature individually. The goal is to find a commonality that will provide interoperability by the addition of a card (hardware) or software, or both, at minimal expense. This will require that the railroads as a body adopt a basic standard for PTC design throughout the industry.

Each PTC system has been designed using a portion of the ATCS specifications, which broadly cover requirements for operating in the railroad environment. The designer of each system followed the ATCS specifications only as they appeared to apply to the system under development. Thus, interoperability between the systems does not exist. One system was designed with proprietary features. Therefore, open architecture does not encompass all the systems.

In some ways, interoperability is a business issue – when railroads develop sufficient run through traffic to justify the expense of interoperable systems that avoid terminal delay in order to expedite the traffic profitably, interoperability will occur. For example, historically the Union Pacific and Chicago Northwestern each had systems that were not compatible. The UP uses a 4-aspect cab signal system that functions on coded track circuits supplemented by automatic trainstop. The CNW system is a 2-aspect train control system that functions on non-coded track circuits -- when the track circuit is energized, the cab indicator displays Clear, when de-energized it displays Restricting and initiates a full-service brake application. Because of the business benefits of running trains through Fremont, Nebraska and avoiding the delays associated with going through Council Bluffs and Omaha, the railroads installed both systems on a dedicated fleet of locomotives which achieved interoperability on about 50 train movements daily.

FRA has worked closely with the AAR, railroads, and vendors involved in the development of these systems. As a result of FRA's efforts, the AAR formed the Implementers Interoperability Task Force, a subcommittee of the AAR's Railroad Operations Communications Strategy Task Force. The Task Force's work is finished and the Task Force has been terminated. The Task Force was composed of representatives from railroads, suppliers, project integrators, AAR and FRA. Its mission was to review minimum interoperability requirements of PTS, ITCS, and PTC and to determine the requirements for resolving incompatibilities. The task force worked to define and document the systems' requirements using ATCS specifications and each system's requirements. However, the results of the group's work can best be described as conceptual. No set of specifications or agreed-upon procedures was adopted, and therefore no conclusion can be drawn about cost effectiveness.

It will be important to find a common ground of agreement as to how interoperability can be achieved. Before this level is reached, it is necessary to understand the components of the different systems and to identify elements in each system that would not allow a particular system to operate successfully within the other's territory. After this knowledge is acquired, what can be added, changed, or possibly deleted in each system can be identified to make interoperability possible. FRA and others are concerned that the AAR efforts to achieve interoperability maybe terminated before results are achieved. Yet Amtrak and the major freight railroads are considering large capital investments that will yield wider safety and business benefits only to the extent interoperability can be achieved. Clearly, this is an arena that warrants early action.

2. Intraoperability

Intraoperability is defined as seamless operations within one railroad. Any discussion of interoperability must include a discussion of intraoperability. It is necessary to determine which Operating Rules are appropriate to handle unequipped trains, roadway workers, and on track equipment, and to define strategies, and how those strategies impact deployment.

The following types of operations raise intraoperability issues including: unequipped foreign line locomotives and home road locomotives, on-board system failures, communications failures, out of communications coverage, whether a part of the design or not, maintenance of way equipment, short line railroads using track rights, and leased locomotive units from third party leasing companies.

From an operating rules consideration, implementing a PTC system can be done in one of three ways:

- A PTC system of the stand-alone type will not only augment the existing signal system but will absorb its functionality to the extent wayside signals may safely be removed. Safety computers at a central office, on the wayside and on-board each locomotive will enforce the proper spacing of trains, all speeds and stop where a stop is required. Stand-alone PTC systems will become the method of train operations.

- PTC systems of the enhanced overlay type will be so interconnected with the existing signal system that its functionalities will be extended to equipment on-board each locomotive that will enforce all speed and stop requirements prescribed by both the PTC and signal systems. The existing method of train operations may or may not change.

- PTC systems of the pure overlay type will provide for among other things, enforcement of all speed and stop requirements while utilizing the existing system as the primary method of train operations.

If any system fails, then the railroad must have sufficient operating rules and instructions that will insure a safe and complete operating transition from current operations.

Some of the systems could work in the background virtually unknown to the train crew. While this has advantages, it would be a significant disadvantage should the train crew rely on the system when it may not be functioning correctly. Everyone that is subject to the operation of system is notified of system in place and operative, including the train crew, train dispatchers, and Roadway employees.

PTC Systems may range in form from highly interactive to totally invisible to the locomotive engineer. The following areas will need to be addressed to integrate PTC into the railroad:

- The operation of equipped and non-equipped trains and how the joint operation is handled, and incorporating roadway worker protection.
- Training for employees in the procedures to activate/deactivate the system, as well as recovering the system if an enforcement occurs.
- Training for employees on procedures for when the system fails.
- When the PTC system functions inappropriately and should be considered failed and deactivated and who needs to be notified.
- Training for employees in the likely failure modes and how those failure modes may be displayed, or the appearance of a display failure.
- Notification to train crews and roadway worker forces of areas where PTC is not operational.
- Processes for initializing and terminating a PTC equipped train.
- Procedures to handle PTC information updates that modify or conflict with the existing authority (e.g., detector activation, crossing malfunction, intrusion).

Existing method of operation rules would apply in failure of any system.

E. Program Elements Models and Simulation Tools

Development of PTC will include a number of program elements to ensure that PTC products from suppliers are safe, cost-effective, interoperable, and maintainable in the railroad environment. The PTC RSAC, which includes the participation of railroads, the FRA, labor, suppliers, and other interested parties, is addressing PTC safety standards and functional requirements.

Elements of a PTC development program may include the following, which are to be used on the joint FRA/IDOT/Industry PTC Program:

Development of Standards and Specifications – A Systems Engineering (SE) Contractor has been competitively selected to support development of the standards and specifications for PTC. The SE contractor is working with the industry to define standards for PTC functionality, interfaces, and performance. These standards will form the basis for development of bid documents to select a System Developer/Integrator (SDI) for implementation of PTC on the Illinois high-speed corridor from Mazonia to Springfield. The competitively-selected SDI contractor will define more detailed interoperability interface specifications for PTC, and will install PTC on the IDOT corridor. The PTC standards and specifications will be used in the procurement of interoperable PTC systems by individual railroads.

PTC Pilot Program – There have been and continue to be a number of pilot programs within the railroad industry to test alternative PTC system approaches and related technologies. The Illinois PTC pilot program is a joint endeavor of the railroads, the FRA, and Illinois DOT. The PTC standards being developed will be augmented with corridor-specific requirements to produce PTC specifications for the Illinois corridor. The pilot system developed and installed in response to these specifications will provide a test bed to prove the viability of PTC concepts and evaluate PTC technologies, and provide standards for interoperable PTC systems. The pilot system program will deploy an operational system for the test bed corridor.

Testing – The Illinois PTC pilot program will include extensive testing of system technologies, operating practices, and rules, as well as a determination of the viability of PTC for real-world installations. Data from this testing will support evaluation of PTC life cycle costs and benefits, as well as PTC performance.

Models – The PTC development program will include development and application of computer-based models to evaluate system performance requirements, design tradeoffs, system costs and benefits, implementation options, and safety impacts.

Simulation Tools – The PTC development program will also include development of simulation tools. Some of these simulation tools will be used to validate PTC system operation. A PTC simulation tester(s) may be developed to determine compliance of PTC products with the standards. Other simulation tools may be used to evaluate the operational impact of PTC, such as the potential improvement in corridor capacity due to flexible block control.

The joint PTC program has as one of its objectives to "provide for industry interoperability, and demonstrate safe operation of locomotives equipped with interoperable systems." This objective will enable equipped trains operating from different railroads to come onto a foreign railroad safely at track speed. To meet this objective the program will consider:

Locomotive human-machine interfaces with a minimum set of standard features, to provide the necessary and expected information for safe operation.

- Compatible communications interface(s) to/from and on-board the locomotive.
- Minimum acceptable content and format of databases.
- Minimum common set of messages between devices and objects (functions) on-board the locomotive/track vehicles and off-board controllers.

Another of the Program objectives is to "provide a cost effective design, in order to enhance prospects for deployment." A cost-effective design will consider the use of commercial off-the-shelf (COTS) equipment made by different manufacturers.

To be successful the industry will require a set of minimum interoperable standards that are unambiguous so that equipment built to these standards will operate correctly and can be proven to operate correctly. The proof can be obtained through extensive field testing, through a combination of field and laboratory testing (simulation) or through simulation alone. Simulation testing is effective in that it can:

- Be more thorough than field testing, by testing scenarios that are either too complex for field testing or too hazardous.

- Provide for more cost-effective evaluations.

There are two categories of simulation tools proposed for the PTC Program. The System Developer/Integrator will need to build a simulator to evaluate the design of the system to be installed in the IDOT test bed from Springfield to Mazonia. The simulator can also be used to evaluate production subsystems and components to assure these devices function properly and meet the specifications.

The second set of simulation tools is to provide a cost effective and consistent means for evaluation of various systems built to industry interoperability standards. This evaluation will determine if the system/components under test will:

- Communicate properly – the simulation tool will test communications interoperability, both wire and wireless. Wired communications will most likely be limited to the on-board data bus. Wireless communications will consist of communications from the on-board system to any designated interoperable device off-board e.g., dispatch office. This on-board/off-board test capability will evaluate the wireless link only.

- Respond correctly to messages - assure the correct response of on-board devices to messages from other on-board and off-board devices.

- Behave correctly - control flow tester to assure industry that modifications to interoperability standards will do what is intended and not degrade or injure existing systems intended to be compatible. This simulation tool will determine if the correct (safe) outcomes result. Testing can include deliberate degradation of the system through removal of components, and fault injection.

The simulation tools are proposed as a way to evaluate systems/components that is less risky and costly than field testing. For instance, fault injection intended to see if two opposing trains will respond correctly is likely to introduce unacceptable risk in field testing. Field testing requires the use of locomotives, communications, and other systems that can be reduced to computers with software in the simulator. In addition, all the testing will be done off line.

Field testing is still recommended for proof of concept and operational evaluation, but most of the safety assurance and system performance evaluations could be done with the simulation tools at much lower cost.

Appendices

A. Glossary of Acronyms and Terms

B. Summary Matrix of Current Positive Train Control Projects

C. Compendium of Current Positive Train Control Projects

D. Benefits and Costs of Applying PTC (Tables)